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Numerical Optimization of Synergetic Maneuvers

by

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June 1994

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Numerical Optimization of Synergetic Maneuvers

by

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ABSTRACT

The use of atmospheric forces to produce an orbital plane change requires less energy than a pure exoatmospheric propulsion maneuver. The combination of aerodynamic and propulsive forces to cause a change in orbital inclination is termed a synergetic maneuver. Several methods have been proposed to control the critical heating rate while performing the procedure. This thesis examines these control methods by numerically optimizing the trajectory for several fuel weights and heat rate constraints. The Program to Optimize Simulated Trajectories (POST) is used to simulate the maneuvers and control schemes and to perform the optimization. For no active heat constraints, it is shown that a gliding atmospheric entry followed by a maximum throttle "bang" produces significantly more inclination change than other proposed maneuvers. If the heat constraints are active, the recently proposed aerobang maneuver produces a substantial inclination change while providing significant heating rate control and shows definite advantages over the long-studied aerocruise maneuver.

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J. C. N.

I. INTRODUCTION

A maneuver using atmospheric forces to assist in orbital plane changes is an alternative to the use of a purely propulsive maneuver. It holds the potential for substantial fuel savings [Ref. 1] and could be an important maneuver for a future transatmospheric vehicle. The practical application of such a maneuver to a lifting body at hypervelocities may soon be within reach. The thermal environment in which a vehicle would have to survive and operate could be severe. New materials, propulsion, and engineering techniques are constantly being explored. It is important that the study of the maneuvers that this vehicle will perform be conducted now, so that an integrated design of vehicle and mission can be conducted in the future.

A. THESIS SCOPE

The basic synergetic maneuver begins with a retrorocket burn causing the vehicle to leave its initial low-earth-orbit (LEO) and begin a shallow atmospheric entry (see Figure 1). During the atmospheric pass, the vehicle is banked so that the lift vector is in a lateral direction, thus producing an aerodynamic turn. If this turn is accomplished with no thrusting, it is termed an "aeroglide" maneuver [Ref. 1]. If it is performed with continuous thrusting sufficient to balance the aerodynamic drag, it is termed "aerocruise" [Ref. 2]. If it is performed with maximum thrusting, it is termed "aerobang" [Ref. 3]. Following the aerodynamic turn, the vehicle is reboosted to the desired orbital altitude with an additional rocket burn to circularize the orbit. These models of thrusting profiles were translated into simulations on NASA's Program to Optimize Simulated Trajectories (POST). Using a point mass model, the thrust force and the angles of attack and bank are considered as the only controls during the atmospheric flight. The results of this program were then analyzed in detail. This thesis makes an analytical and numerical comparison between the types of maneuvers currently proposed, summarizes the differences, and concludes with a recommended "optimal" maneuver.

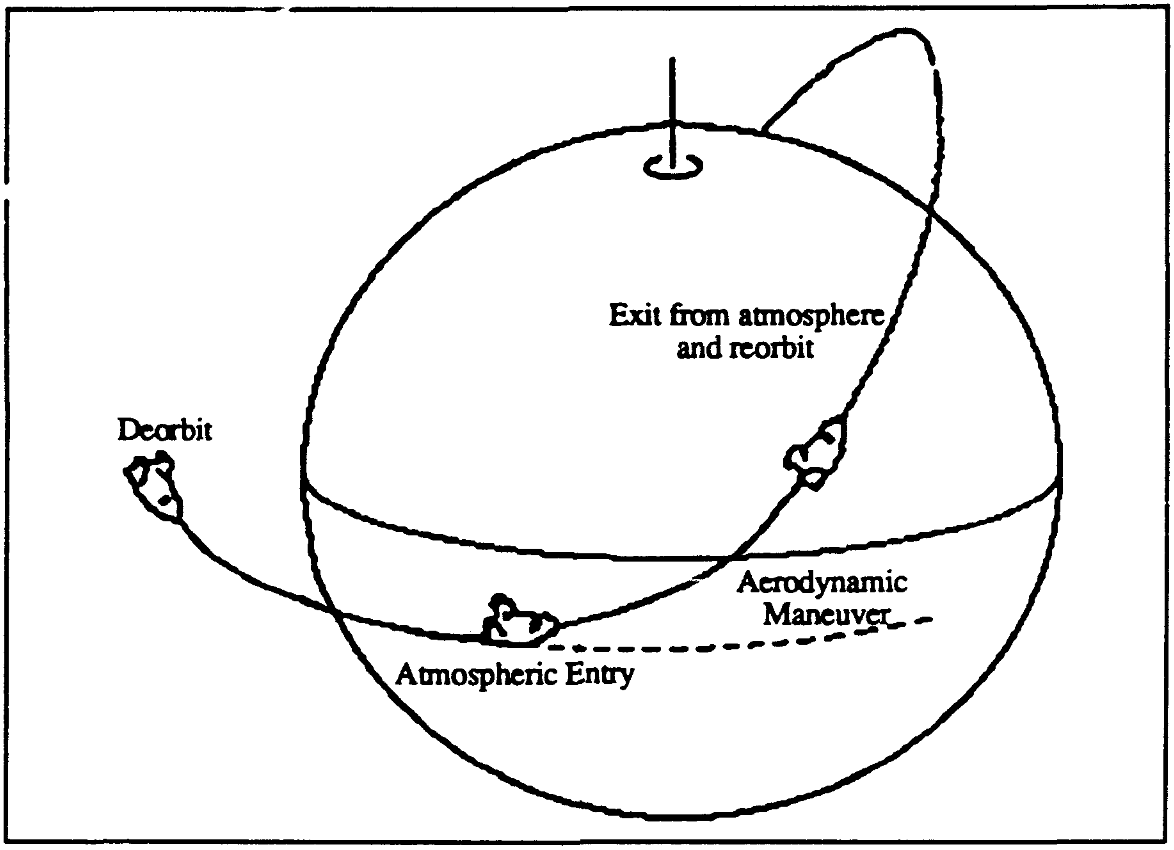

Figure 1. Synergetic Plane Change Maneuver [Ref. 1:p. 4]

B. BACKGROUND

The pioneering work of London [Ref. 4] in 1961 first demonstrated that the use of aerodynamic forces in combination with propulsive forces could produce an orbital plane change with a substantial performance gain over a pure propulsive maneuver. This type of aeroassisted maneuver was dubbed a synergetic plane change and is but one member of the class of aeroassisted maneuvers. Other applications include transfers between high and low coplanar orbits and aerocapture or aerobraking which has uses in planetary missions. Aerobraking has recently been used in the Magellan mission to Venus. This thesis only examines the synergetic plane change.

1. Historical

During the 1960's synergetic plane change was studied extensively, with most of the early analyses point-mass trajectory examinations in which the emphasis was on defining the theoretically achievable plane changes and corresponding ΔV requirements, rather than on design details of a vehicle [Ref. 1:p. 6]. The initial motivation for this work was the recognition that orbital plane changes required very large characteristic velocities (ΔV). In fact, it was pointed out [Ref. 2] that a single-impulse 60 degree plane change required as much ΔV as that required to place the satellite in LEO in the first place. As studies progressed, it became evident that the same type of high L/D (lift to drag ratio) vehicle could also perform Earth return missions with a large cross-range capability, perform evasive maneuvers, and have considerable military importance.

The first quantity measured in these studies was the synergetic efficiency, defined as the ratio of the orbital plane change achieved (expressed in radians) to the required ΔV (normalized by the satellite velocity, V_c). For a single, all-propulsive maneuver performed outside the atmosphere, the efficiency is almost unity. Two of the main conclusions drawn by early investigators [Ref. 1:p. 5] were that it was desirable to maximize the vehicle's L/D and that it must be significantly higher than 1.0 if the synergetic maneuver is to be superior to an all-propulsive maneuver. These early conclusions also included that the maneuver should be carried out at $(L/D)_{max}$. The major problem with this conclusion is that vehicles flying at $(L/D)_{max}$ experience very high integrated heat loads and high L/D configurations are typically slender bodies with small nose radii and hence, high stagnation-point heating rates.

An analysis of entry vehicles of the time [Ref. 5] suggested that a large reduction in heat load could be achieved by carrying out a short duration, high angle of attack turn rather than a gradual $(L/D)_{max}$ turn. Of course turns performed at these higher angles would generate increased acceleration loads. A third constraint that was brought out later [Ref. 6] is the necessity of completing the turn in a relatively short amount of time. A turn performed at the orbit node is more effective in changing the orbit inclination while a turn

performed at the orbit apex actually produces only a change in the location of the orbital nodal crossing. Hence if a turn lasts a long time (half an orbit, for example) it is essentially wasted from the standpoint of orbit inclination change.

Lau [Ref. 7] first examined these several constraints (heating, acceleration, range) together to determine the maneuvering envelope of a space vehicle. He concluded that the heating rather than the acceleration constraint usually fixed the upper boundary of the maneuvering region. Later investigators [Ref. 6] refined his maneuvering envelope by adjusting for the decrease in $(L/D)_{max}$ with increasing altitude.

The two turning techniques most studied by investigators during this period (through the 1980's) were the aeroglide and the aerocruise. When realistic temperature constraints are imposed on the turning vehicle, the thrusting turn (aerocruise) had been shown to have significant advantages over the gliding turn [Ref. 8]. The explanation for this is that while an aeroglide vehicle is continuously decelerating and descending through the atmosphere it will encounter high heating rates on the vehicle. During this heating region, the vehicle must fly at reduced bank angles to avoid exceeding the surface temperature limits and, therefore, has less turning capability. Only after the vehicle has decelerated through the peak heating region can it resume high bank angles and complete the turn. The aerocruise vehicle, on the other hand, employs continuous thrusting sufficient to balance aerodynamic drag and maintain a high enough altitude throughout the turn without exceeding the heat constraints.

More recent studies of synergetic plane change have analyzed several of the proposed hypersonic vehicle designs, the MRRV (maneuverable re-entry research vehicle) and the ERV (entry research vehicle). With more exact models to work from, optimization of the maneuvers has taken place to maximize the inclination change for a given amount of fuel [Ref. 9]. Numerical solutions of these optimization problems have brought additional complexity to the hypersonic vehicle design as well as more exact solutions to the synergetic turn. It was shown [Ref. 10] that minimal fuel aerocruise will require flight on the heat rate constraint boundary at high angles of attack. Recently, it

has come to light that the aerocruise maneuver may not be optimal and that a new maximum-thrust maneuver termed aerobang may yield a better performance [Ref. 11]. This maneuver uses more of the thrust and bank angle to perform the turn and allows the angle of attack to control the heating rate.

2. Current Status

The history and evolution of the synergetic turn has been established, and now the particulars of each type of maneuver are reviewed.

a. Aeroglide

In the aeroglide mode, no propulsive forces are used (during the aerodynamic turn), the vehicle performs the plane change solely with the lift generated by the vehicle surfaces. The lift generated is normal to the orbit plane and the angle of attack is usually close to $(L/D)_{max}$. In order to generate the necessary lift, the vehicle is flown at speeds and altitudes where the atmosphere is more dense which results in high heating rates, possibly beyond the capabilities of a thermal protection system. If the heating rate is not a problem, the only fuel expenditure would be to deorbit and reorbit which has been shown to be significantly less than the pure propulsive case. [Ref. 12]

b. Aerocruise

In this mode, propulsive forces are used as an additional control during the aerodynamic turn. The most studied form of aerocruise is the steady-state aerocruise where a thrust-drag cancellation produces a cruise trajectory that maintains a constant heating rate. The vehicle is thus locked on to a point on the heat rate constraint boundary. Banking the vehicle allows for a component of lift to counteract the centrifugal force and adjust to non-circular speeds and various altitudes. It was originally thought that the vehicle would fly at $(L/D)_{max}$, but studies [Ref. 9] have since shown that aerocruise is more efficient (greater change in inclination per amount of fuel) at higher angles of attack. As previously mentioned, one reason for this is the length of the aerodynamic arc; it must be

long enough to generate an integrated lift force to perform a meaningful plane change but short enough to concentrate the turn at the orbital node [Ref. 13].

c. Aerobang

In this maneuver, the heating rate is maintained at a constant value but the vehicle is allowed to change its altitude and speed. Thus the trajectory is not circular but a path defined by the heating rate constraint. The vehicle flies at full throttle and the angle of attack is modulated to control the heating rate. The bank angle may be optimized to maximize the inclination change. [Ref. 3]

C. SUMMARY

As with most theoretical maneuvers, the synergetic plane change has been examined and analyzed closely since it was first proposed 35 years ago. As knowledge of the operating environment and required vehicle characteristics has increased, the complexity of the problem has also increased.

It is clear that these three maneuvers achieve the inclination change in significantly different ways. Further, if the vehicles heat protection system is sufficient, then the aeroglide maneuver offers improved performance as it involves no thrusting during the maneuver turn. Given that the heating rate is an active constraint, this thesis compares the optimal synergetic maneuvers and attempts to recommend a "best" maneuver for a given fuel expenditure or required plane change.

II. THEORETICAL FORMULATION

The equations of motion for a hypervelocity lifting body are presented here with accompanying assumptions. It is important to note the relation that is developed between these equations and the orbital elements, as this provides the basis for comparison of orbits and maneuvers. The control laws for the synergetic maneuvers are also presented, with a brief summation of their derivation. The aerocruise and aerobang have unique methods for controlling the vehicle's trajectory and heating rate during the atmospheric encounter. This difference significantly effects the final results.

A. EQUATIONS OF MOTION

The equations of motion for the aeroassisted maneuver can be broken down into three basic stages. The first stage is the transition of a body from a circular orbit into a descending elliptical orbit that will cause the body to enter the atmosphere. The next stage is the atmospheric portion, where the body will encounter aerodynaimc lift and drag forces. The final stage is the boost from the atmosphere back into orbit and any circularization that is required. The equations for the space portion of the maneuver are readily defined in terms of the standard Keplerian elements. A closer examination of the atmospheric portion of the trajectory is required.

The equations of motion for a lifting body in an inverse-square gravity field are presented next. These equations in spherical coordinates were first derived by Vinh [Ref. 14], and assumed a spherical central body and a nonrotating atmosphere. The vehicle is a point mass that is experiencing aerodynamic forces. The state variables are:

r - radial position of the vehicle,

v - vehicle velocity,

γ - flight path angle,

θ, φ, ψ - longitude, latitude, heading angle.

These variables are identified in Figure 2.

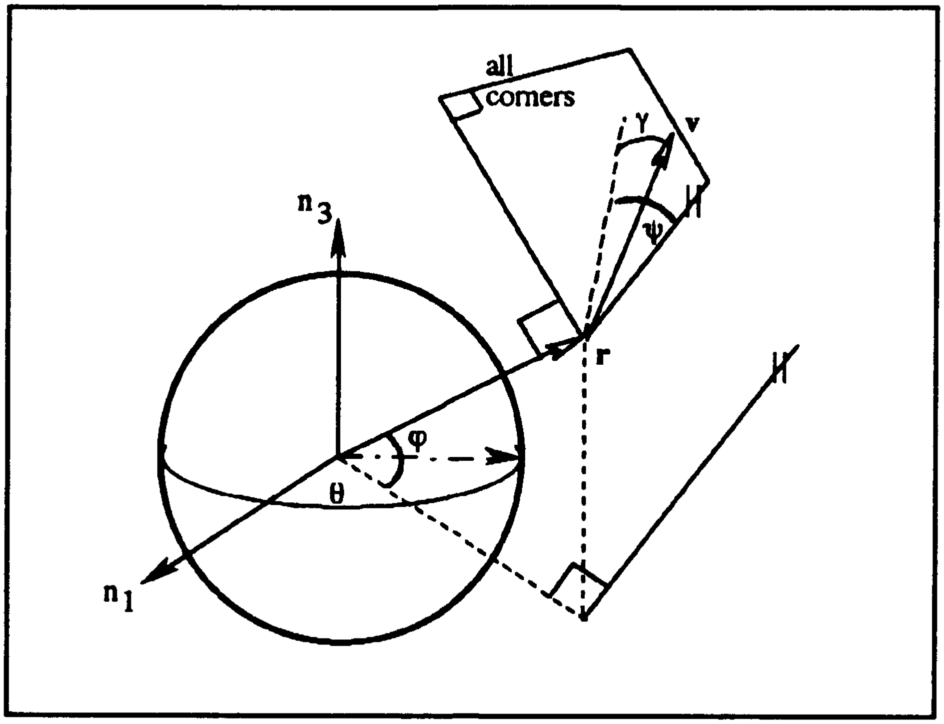

Figure 2. Depiction of State Variables

The equations of motion are:

$$\frac{dr}{dt} = v\sin\gamma$$

$$\frac{dv}{dt} = A_S - g\sin\gamma$$

$$v\frac{d\gamma}{dt} = A_R - g\cos\gamma + \frac{v^2}{r}\cos\gamma$$

$$\frac{d\theta}{dt} = \frac{v\cos\gamma\cos\psi}{r\cos\varphi}$$

$$\frac{d\varphi}{dt} = \frac{v\cos\gamma\sin\psi}{r}$$

$$v\frac{d\psi}{dt} = \frac{A_W}{\cos\gamma} - \frac{v^2}{r}\cos\gamma\cos\psi\tan\varphi$$

where

$$g = \frac{\mu}{r^2}$$

and A_S, A_R, and A_W are the perturbing accelerations in the tangential, "radial," and binormal directions.

The vehicle's mass may be found by the rocket equation

$$\frac{dm}{dt} = -\frac{T}{I_{SP}\, g_0}$$

where T is thrust, I_{SP} is specific impulse, and g_0 is the gravitational force at the planet surface. It has been shown [Ref. 15] that the inclination is related to these state variables by

$$\cos i = \cos \psi \ \cos \varphi .$$

From the free body diagram shown in Figure 3, the accelerations mentioned above are given by

$$A_S = \frac{T\cos\alpha - D}{m}$$

$$A_R = \frac{(L + T\sin\alpha)\cos\delta}{m}$$

$$A_W = \frac{(L + T\sin\alpha)\sin\delta}{m}$$

where L and D are the aerodynamic lift and drag, m is the vehicle mass and α and δ are the angles of attack and bank. Note that the thrust vector is fixed along the reference body axis of the vehicle from which α is measured as well.

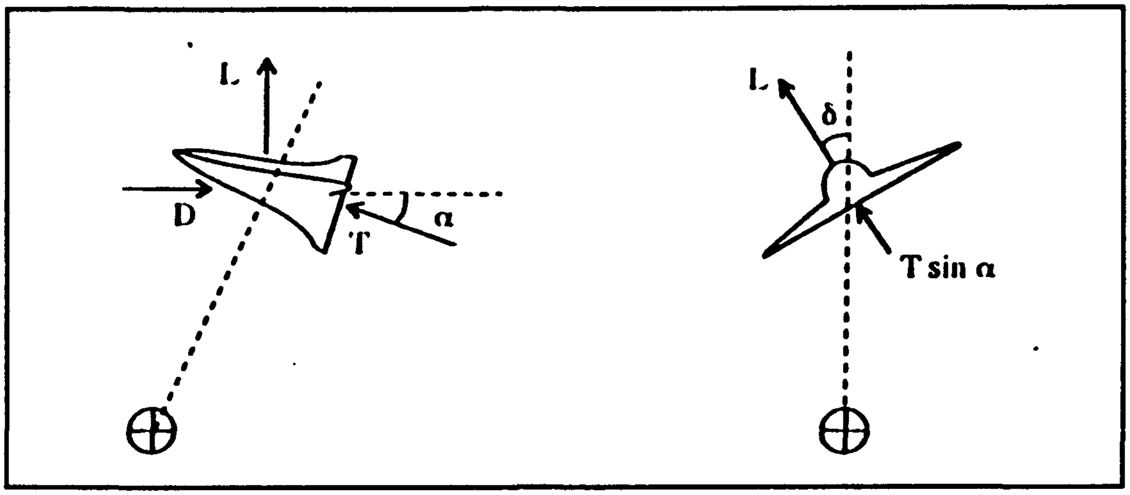

Figure 3. Forces Exerted on Lifting Vehicle [Ref.3:p. 4]

B. CONTROL LAWS

1. Aeroglide

The control laws used during the atmopheric portion of flight vary acording to the maneuver. The aeroglide maneuver does not account for any heating encountered during the atmospheric pass. The vehicle performs a gliding turn into the atmosphere, using the lift generated by its surfaces. At a particular point, depending on the inclination change required and fuel available, the engines are brought on-line and a maximum thrust boost to orbit altitude is conducted. This boost is termed an "unconstrained bang" or "bang" in this thesis, due to the absence of heat constraints and the maximum throttle setting.

The control laws for the glide portion are:

$$T = 0$$
$$\alpha = \text{free variable}$$
$$\delta = \text{free variable}$$

while the control laws for the unconstrained bang portion are:

$$T = T_{MAX}$$
$$\alpha = \text{free variable}$$
$$\delta = \text{free variable}$$

2. Aerocruise

Aerocruise , in general, refers to the use of thrust during the atmospheric portion of the flight trajectory. The simplest and most studied form of this is the steady–state aerocruise in which the component of thrust along the velocity vector is adjusted to cancel drag and the vertical components of thrust and lift are used to maintain a constant radius and speed (and hence heating rate). Applying this to the accelerations yields,

$$A_S = 0$$

$$A_R = g - \frac{v^2}{r}$$

which yields the control programs

$$T = \frac{D}{\cos\alpha}$$

$$\cos\delta = \frac{m\left(g - \frac{v^2}{r}\right)}{L + T\sin\alpha}$$

$$\alpha = \text{ free variable}$$

3. Aerobang

The first step in modeling the aerobang control law for a hypersonic lifting vehicle is done by examining the formula for aerodynamic heating. Chapman's equation is a simple method that is generally used [Ref. 16]

$$\frac{dq}{dt} = C\rho^N v^M$$

where N is equal to 0.5, M is equal to 3.15, and C is a constant adjusted for units. This equation provides the stagnation point heating rate, usually identified as the most critical factor. It turns out that the individual constants are not as important as the parameter

$$\xi = \frac{\beta N}{M}$$

where β is the scale factor used in approximating the variation in the local density of air, ρ, by the exponential model

$$\rho = \rho_0 \exp\{-\beta(r - r_0)\}$$

where r is the radial distance from the earth's center. It has been shown [Ref. 3] that the tangential acceleration for the aerobang maneuver reduces to

$$A_S = (g + v^2 \xi) \sin \gamma$$

which translates to a control program for the angle of attack (since drag is also an explicit function of α). Thus, the control programs are,

$$T = T_{MAX}$$

$$T \cos\alpha \; - \; D(\alpha) = m \; \sin\gamma \, (g + v^2 \xi) \text{ yields } \alpha$$

$$\delta = \text{free variable}$$

C. ANALYSIS

The basic scheme of the aeroassisted maneuver is now established. For a given vehicle model, a simulation of a deorbit , atmopheric entry, aerodynamic maneuver, boost and reorbit can be conducted. The challenge then, is to determine what control history should be followed to maximize the inclination change for a given amount of fuel. If, in the course of flight, the heating rate on this vehicle model goes beyond its thermal protection limits, which scheme (aerocruise or aerobang) will be more effective (in terms of thermal contrc! and inclination change)?

A first inspection of these maneuvers would indicate that the largest inclination change would be obtained with the glide-unconstrained bang profile. The amount of force required to "pull out" the vehicle from its descent and then boost it to orbit is approximately the same for each maneuver. With no heat rate constraints, the remaining control force in the glide-bang could be used to bank the vehicle, thus maximizing the inclination change.

If the heat rate constraint is active, some of the available control forces would have to be used to reduce the heating rate to acceptable levels. Comparing the two sets of controls (cruise and constrained bang), it is clear that the two have interchanged the roles of angle of attack and bank angle. While both may effectively reduce the heating enviroment, aerobang has allowed the bank angle to remain "free." This should allow more of a turn to be conducted and hence more inclination change than the steady-state aerocruise.

The next step is to translate the problem into a series of equations with constraints that are active in different phases. To determine the best or "optimal" maneuver, the control variable history would have to maximize the inclination change while satisfying all the constraints. A program must be used that will integrate the equations of motion each step of the problem and satisfy constraints along the way. Not only must the solution be feasible in terms of constraints, it also must be the optimal solution. Such an algorithm exists in NASA's Program to Optimize Simulated Trajectories (POST). Before the details of implementing POST are covered, a review of basic numerical optimization techniques will be conducted.

III. NUMERICAL OPTIMIZATION

Before the equations of motion and the various control methods for the aeroassisted maneuver can be implemented, it is important to develop a background for the type of problem being studied here. It is more than just getting the space vehicle from point A to point B. It is *how* that vehicle gets from point A to point B. Is there only one unique way of getting from here to there? Are there any constraints on our controls or motion that must be observed? Is there a parameter that should be optimized (maximized or minimized)? In general, this type of problem falls into the realm of *functional optimization.* Such problems have been successfully solved by nonlinear programming methods and this chapter discusses the basic optimization problem, some current numerical methods of solving these problems, and the targeting/optimization routine used in the program that will simulate and optimize the proposed aeroassisted maneuvers.

A. BASIC PROBLEM STATEMENT

Consider the following problem:

$$
\begin{aligned}
&\text{Maximize} && f(\mathbf{x}) \\
&\text{Subject to} && g_i(\mathbf{x}) \leq 0 \quad \text{for } i = 1, \ldots, m \\
& && h_i(\mathbf{x}) = 0 \quad \text{for } i = 1, \ldots, l \\
& && \mathbf{x} \in \mathbf{X}
\end{aligned}
$$

where f, g_i, h_i are functions defined on $\mathbf{E}_n$, where $\mathbf{E}_n$ is Euclidean space, the collection of all vectors of dimension n. $\mathbf{X}$ is also a subset of $\mathbf{E}_n$ and $\mathbf{x}$ is a vector of n components. (Note that italicized variables are functions and bold-faced variables are vectors.)

The function f is usually called the objective function with $g_i(\mathbf{x}) \leq 0$ termed an inequality constraint and $h_i(\mathbf{x}) = 0$ termed an equality constraint. A vector $\mathbf{x} \in \mathbf{X}$ satisfying all constraints is called a feasible solution or trajectory. The problem then is to find a feasible point $\mathbf{x}^*$ such that $f(\mathbf{x}) \leq f(\mathbf{x}^*)$ for each feasible point $\mathbf{x}$. A point $\mathbf{x}^*$ is called the optimal solution to the problem.

B. ALGORITHMS AND CONVERGENCE

1. Summary of Convexity and Optimality Conditions

The function f is said to be convex if

$$f[\lambda \mathbf{x}_1 + (1 - \lambda)\mathbf{x}_2] \leq \lambda f(\mathbf{x}_1) + (1 - \lambda) f(\mathbf{x}_2)$$

for each $\mathbf{x}_1$, $\mathbf{x}_2 \in \mathbf{E}_n$ and for each λ between 0 and 1 ($\lambda \in [0,1]$). Figure 4 is an example of a convex function.

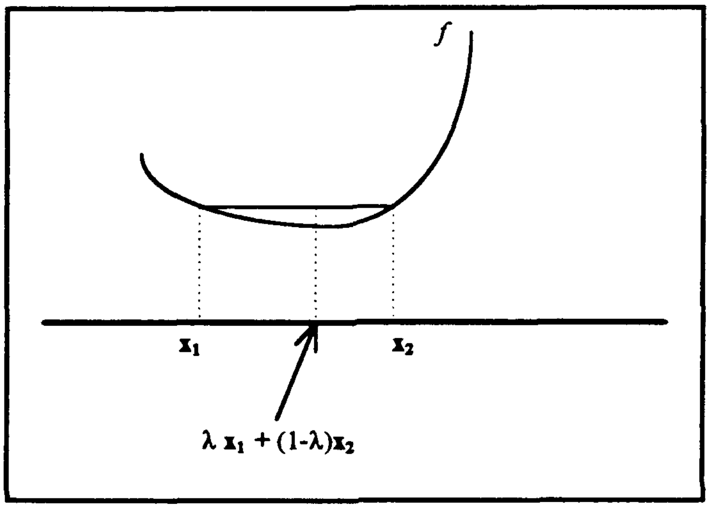

Figure 4. Convex Function

The assumption of convexity of a function can be relaxed to the less stringent concepts of quasiconvex and pseudoconvex functions. The function f is said to be quasiconvex if

$$f[\lambda \mathbf{x}_1 + (1 - \lambda)\mathbf{x}_2] \leq \text{maximum } \{f(\mathbf{x}_1), f(\mathbf{x}_2)\}$$

with λ and $\mathbf{x}_1$, $\mathbf{x}_2$ holding the same characteristics as in the convex example. The function f is said to be pseudoconvex if, for each $\mathbf{x}_1$ and $\mathbf{x}_2$ with $\nabla f(\mathbf{x}_1)^t(\mathbf{x}_2 - \mathbf{x}_1) \geq 0$, there is $f(\mathbf{x}_2) \geq f(\mathbf{x}_1)$. These concepts are depicted in Figure 5. [Ref. 17]

There are several important properties of these functions. For a convex function f, every local minimum of f is the unique global minimum. For pseudoconvex functions, every local minimum of f over a convex set is a global minimum. For quasiconvex functions, a local minimum of f over a convex set does not guarantee a global minimum. Although minimum is the term used here, this applies to maximum points as well.

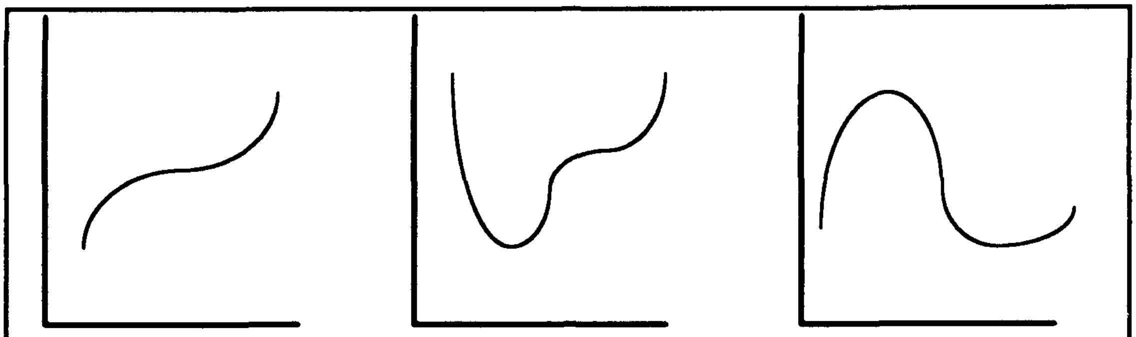

Figure 5. Quasiconvex and Pseudoconvex Examples

Consider again the problem described in Section A, maximizing a function subject to inequality and/or equality constraints. One of the important optimality conditions is termed the Karush-Kuhn-Tucker (KKT) conditions. These necessary optimality conditions begin with $\mathbf{x}^*$ as a local optimal solution to the problem. Then, with suitable constraint qualification, it can be shown [Ref. 17] there exists a vector $(\mathbf{u},\mathbf{v})$ such that

$$\nabla f(\mathbf{x}^*)+\sum_{i=1}^{m}\mathrm{u}_i\nabla g_i(\mathbf{x}^*)+\sum_{i=1}^{l}\mathrm{v}_i\nabla h_i(\mathbf{x}^*)=0$$

$$\mathrm{u}_i\, g_i\,(\mathbf{x}^*)=0 \quad \text{for } i=1,\ldots,m$$

$$\mathrm{u}_i \geq 0 \quad \text{for } i=1,\ldots,m$$

where u_i and v_i are Lagrangian multipliers associated with the constraints $g_i(\mathbf{x}) \leq 0$ and $h_i(\mathbf{x}) = 0$. This concept is essentially one of "setting the derivative equal to zero" from introductory calculus. These conditions are developed further in References 17, 18, 19.

2. Convergence Algorithms

Beginning with the basic optimization problem, a desirable property of any algorithm would be that it generates a sequence of points converging to a global optimal solution. In many cases, less favorable outcomes result from nonconvexity, problem size, or computing difficulty due to poor initial inputs. Most algorithms cannot confirm that

they are at a global optimum, so a solution is found that is a local optimum, within a specified tolerance of an acceptable objective value, or one that satisfies the KKT optimality conditions. [Ref. 17:p. 231]

Several important factors must be considered when assessing the effectiveness of any optimization algorithm. These factors include (i) generality, (ii) reliability, (iii) precision, (iv) sensitivity to parameters, (v) preparational effort, and (vi) convergence. Generality refers to the variety of problems an algorithm can handle and the restrictiveness of any required assumptions. These assumptions include unconstrained problems, differentiable functions, linear or nonlinear constraints, etc. The reliability of an algorithm means the ability of the procedure to solve most of the problems for which it was designed with reasonable accuracy. Precision of an algorithm is the quality of points produced after a reasonable number of iterations. The sensitivity to parameters is important because most algorithms require a user specified set of input values for certain variables. A "good" algorithm would be relatively insensitive to the input data, and produce similar results regardless of input values. The preparational effort that an algorithm requires is also a factor in determining the effectiveness. If first- or second-order derivatives are required for computation, then the amount of work expended may be prohibitively large. Finally, the convergence of the algorithm to points in the solution set is highly desirable as stated previously. This could be either in terms of order of convergence or speed of convergence, or both. [Ref. 17:pp. 241-243]

3. Unconstrained Optimization

Unconstrained optimization deals with the problem of maximizing or minimizing a function in the absence of any restrictions. Even though most practical problems have side restrictions that must be satisfied, unconstrained optimization techniques are important because many algorithms solve constrained problems by converting it into a sequence of unconstrained problems. This could be done via Lagrangian multipliers or with penalty functions. Other methods find a search direction and minimize along this direction using unconstrained techniques. The main techniques discussed here are

multidimensional searches using derivatives and methods using conjugate directions. [Ref. 17:pp. 252-253]

Most optimization methods use search techniques to find the optimal solution. Determining the "best" search direction is significant in reducing the amount of time required and the precision of the solution obtained. Two techniques that use derivatives in determining search direction include the steepest descent method and Newton's method.

The method of steepest descent, or the gradient method, is a fundamental procedure for minimizing a function of several variables (Figure 6). If a function f is differentiable at $\mathbf{x}$ with a nonzero gradient, then

$$-\nabla f(\mathbf{x})/\|\nabla f(\mathbf{x})\|$$

is the direction of steepest descent. The function is then evaluated along this direction, a

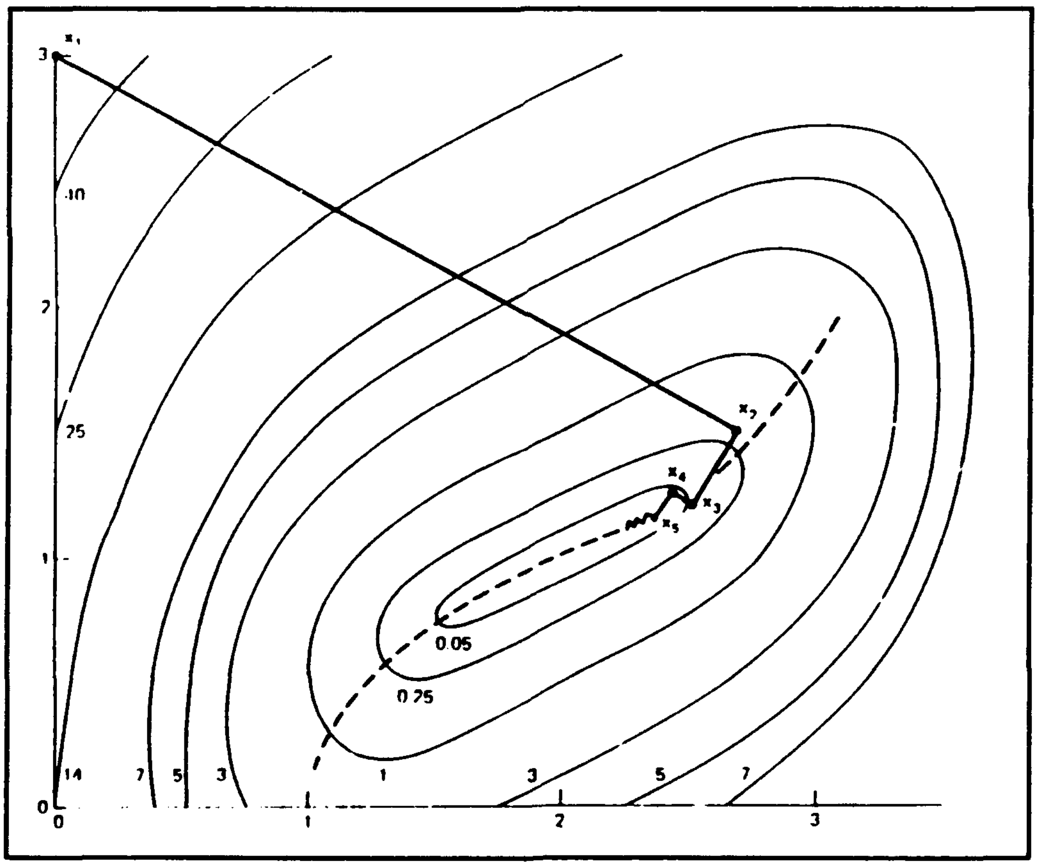

Figure 6. Method of Steepest Descent [Ref. 17:p. 292]

local minimum is found, and another gradient is taken. If this gradient is still nonzero, the process is repeated in this new direction until a minimum point is found, usually determined by finding a zero gradient (or within some tolerance limit of zero). This method works quite well in the early stages of the optimization process, until quite close to the solution, where small orthogonal steps (zigzagging) can occur. [Ref. 17:pp. 289-292]

The method of Newton is similar to the gradient method (Figure 7), but it deflects the steepest descent direction by premultiplying it by the inverse of the Hessian matrix. [Note: The Hessian matrix is merely the function f twice differentiated. Hence the element in row i and column j of the Hessian matrix is the second partial $\partial^2 f(\mathbf{x})/\partial \mathbf{x}_i \, \partial \mathbf{x}_j$.] This procedure is motivated by finding a suitable direction for the quadratic approximation of the function rather than a linear approximation as in the

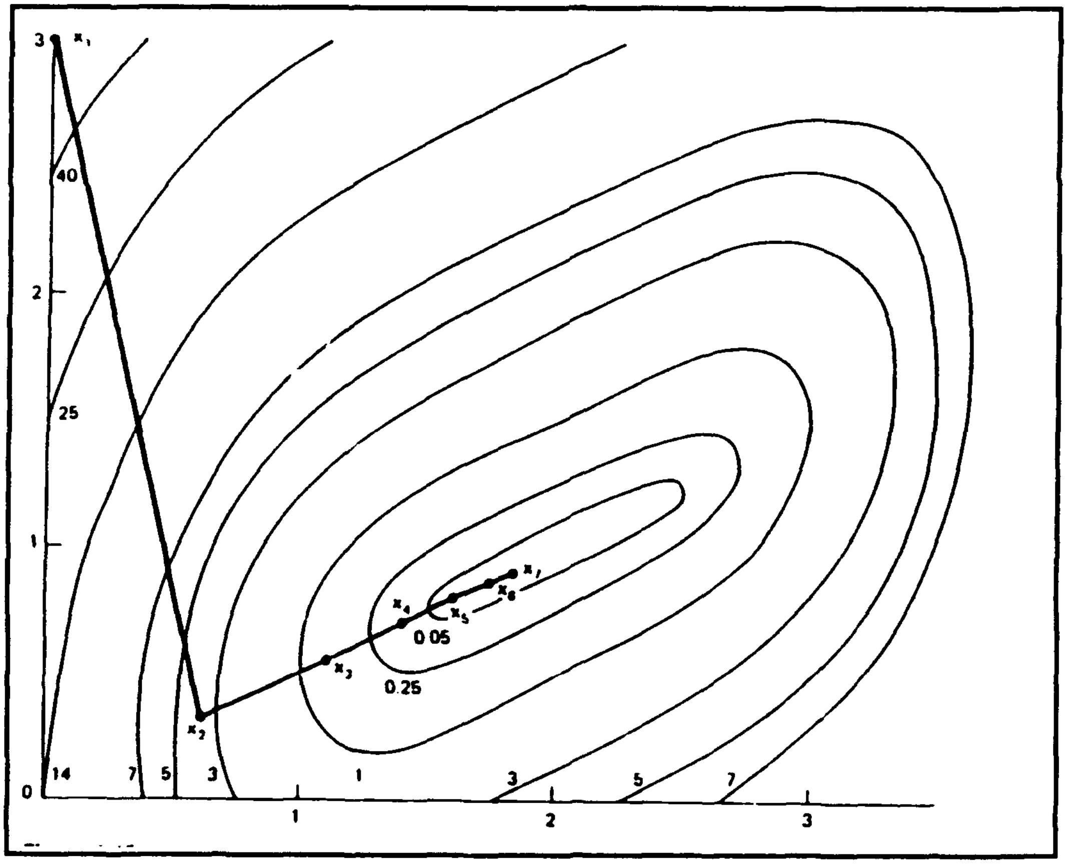

Figure 7. Method of Newton [Ref. 17:p. 295]

gradient method. However, the points generated by the method of Newton may not converge if the Hessian is singular. If the Hessian exists, is of full rank, and the starting point is not far from the optimal, then the method of Newton works quickly and quite precisely. [Ref. 17:pp. 292-295]

The notion of conjugacy is very useful in unconstrained optimization. Minimum points can be obtained rapidly by searching along conjugate directions. These directions can be derived from the Hessian, an n x n symmetric matrix. The vectors $\mathbf{d}_1, \ldots, \mathbf{d}_k$ are called **H**-conjugate or simply conjugate if they are linearly independent and if $\mathbf{d}_i^t \mathbf{H} \mathbf{d}_j = 0$ for $i \neq j$. It has been proved that a quadratic function can be minimized in n steps provided that the search is conducted in conjugate directions of the Hessian matrix [Refs. 17,18]. Since a general function can be closely approximated by a quadratic approximation in the vicinity of the optimal point, conjugacy can be useful for nonquadratic functions as well. Several methods of generating conjugate directions are available, the two discussed here are Davidon-Fletcher-Powell and the method of Fletcher and Reeves. [Ref. 17:p. 298]

The Davidon-Fletcher-Powell method is also termed the variable metric method and is a quasi-Newton procedure. The gradient search direction is deflected by multiplying it by a positive definite symmetric matrix that approximates the inverse of the Hessian matrix. This positive symmetric matrix is then updated to form a new deflection matrix that will affect the next gradient. [Ref. 17:p. 300]

The conjugate gradient method, credited to Fletcher and Reeves, deflects the steepest descent direction by adding to it a positive multiple of the direction used in the previous step. Deflecting the steepest descent direction in this fashion produces a set of conjugate directions. [Ref. 17:p. 306]

Although the term minimization was used extensively in describing these procedures, maximization of functions could also occur by minimizing their inverse. A more in-depth discussion of these and other unconstrained optimization techniques is available in the previously listed references or any text on nonlinear programming.

4. Penalty Functions

Optimization problems with equality and inequality constraints require different techniques to solve. The approach used is to convert the problem into an equivalent unconstrained problem so that previous algorithms can be used. The approach discussed here involves the penalty function method, in which a penalty term is added to the objective function for any violation of the constraints. This method generates a sequence of infeasible points whose limit is an optimal solution to the original problem. [Ref. 17:p. 331]

Methods using penalty functions transform a constrained problem into a single unconstrained problem or a sequence of unconstrained problems. The constraints are placed into the objective function via a penalty parameter that alters the objective function whenever there is any violation of the constraints. The solution to the penalty problem can be made close to the optimal solution as long as the value of the penalty parameter is sufficiently large. This large value can cause some computational difficulties because of ill-conditioning. With a large penalty parameter, more emphasis is placed on feasibility and most unconstrained optimization procedures will then quickly move to a feasible point. Most current algorithms employing penalty functions employ a sequence of increasing penalty parameters. With each new value of the penalty parameter, an optimization technique is employed that uses the optimal solution corresponding to the previously chosen parameter value. [Ref. 17:pp. 332-340]

Several extensions have been made to the concept of penalty functions. In order to avoid the difficulties associated with ill-conditioning as the penalty parameter approaches infinity, parameter-free methods have been proposed. Another development is the use of both a Lagrangian multiplier term and a penalty function term in the auxiliary function. This is also to avoid ill-conditioning. The last and most current research area is in developing auxiliary functions that, for a parameter choice, will yield a solution with a single unconstrained optimization iteration. This is termed an exact penalty function method. [Ref. 17:pp. 358-359]

5. Feasible Directions

This method solves an optimization problem by moving from a feasible point to an improved point. The following strategy is used in these algorithms. Given a feasible point $\mathbf{x}_k$, a direction $\mathbf{d}_k$ is determined such that (for small $\lambda > 0$); $\mathbf{x}_k + \lambda \mathbf{d}_k$ is better than the objective value at $\mathbf{x}_k$. After such a direction is determined, a one-dimensional optimization problem is solved to calculate how far to move in direction $\mathbf{d}_k$. This leads to a new point $\mathbf{x}_{k+1}$, and the process is repeated. The two methods discussed here are Rosen's gradient projection method and Wolfe's reduced gradient method. [Ref. 17:p. 360]

The gradient projection method of Rosen begins with the direction of steepest descent. In the presence of constraints, moving along the steepest descent direction may lead to infeasible points. This method projects the negative gradient of the objective function on the null space of the gradients of the binding constraints. This improves the objective function and maintains feasibility. In the linear case, this leads to an improving feasible direction or to a nearby Karush-Kuhn-Tucker point. In the nonlinear case, the same improvements will be made, but an additional correction to maintain feasibility must be included. An interesting note about the gradient projection method is that there exists neither a convergence proof nor a counterexample of this technique. [Ref. 17:pp. 389-399]

The method of reduced gradient of Wolfe is another procedure for generating improved feasibility directions. The method depends upon reducing the dimensionality of the problem by representing all the variables in terms of an independent subset of the variables. An improved feasible direction is then determined based on the gradient vector in the reduced space. The algorithm has proved to converge to a Kurush-Kuhn-Tucker point, provided that the subset of variables is chosen correctly.

C. TARGETING AND OPTIMIZATION IN POST

The Program to Optimize Simulated Trajectories (POST) uses an accelerated projected gradient algorithm (PGA) as the basic targeting/optimization technique. PGA is

a combination of Rosen's projection method for nonlinear programming and Davidon's variable metric method for unconstrained optimization. [Ref. 20]

The projected gradient algorithm is an iterative technique designed to solve a general class of nonlinear programming problems. PGA employs cost-function (previously termed the objective function) and constraint-gradient information to replace the multidimensional optimization problem by an equivalent sequence of one-dimension searches. In this manner, it solves a difficult multidimensional problem by solving a sequence of simpler problems. In general, at the initiation of the iteration sequence, PGA is primarily a constraint-satisfaction algorithm. As the iteration process proceeds, the emphasis changes from constraint satisfaction to objective function reduction.

All the targeting and optimization procedures used in POST are completely numerical. These means that all the function evaluations and derivatives used by the various algorithms are computed numerically from only the trajectory simulation results. Thus, only defining a problem formulation consistent with the vehicle simulation is required; the program automatically does the rest. This numerical approach is somewhat slower than some analytical methods, but it also provides several advantages such as ease of input, "hands-off" flexibility, greater generality, and minimal program maintenance. [Ref. 21]

1. Problem Formulation

Discrete parameter methods provide the basis of the targeting and optimization formulation and solution algorithms employed in POST. The use of the discrete parameter approach means that trajectory control variables are defined by a finite set of parameters, called independent variables, and given values for these variables the trajectory can be uniquely computed. This discrete parameter approach to trajectory optimization has replaced the more complex calculus of variation techniques because the discrete parameter methods are simpler to implement, understand, and use, and are substantially more reliable. One of the reasons for this is that discrete parameter methods

are based on ordinary vector calculus, vice the more complex variational trajectory programs.

Using discrete parameter concepts, a wide variety of trajectory optimization and targeting problems can be formulated that have a common mathematical structure. To begin, there is a vector **u** of control parameters which must be selected to define the trajectory

$$\mathbf{x}(t) = \phi(\mathbf{x}, \mathbf{u}, t; \mathbf{x}_0)$$

where the state variable **x** is composed of the elements of the vehicle's position, velocity, and mass and ϕ denotes the numerical integration of the equations of motion. Next, for each trajectory problem there is a vector of constraints called dependent variables, y(**u**). These constraints are calculated at particular events and the dependent variables are computed as functions of the independent variables, **u**.

The number of constraints can be less than, equal to, or greater than the number of control parameters. Only if the number of constraints is less than the number of control parameters can some performance criteria be optimized while still satisfying the constraints. So for each trajectory, **x** (t), there is an objective function f (**u**), which is calculated in the same manner as the constraints. The object of the problem is then to determine the control parameters, **u**, which are feasible in that all constraint parameters are within their limits and optimal in that the objective function is maximized (or minimized).

The general discrete parameter trajectory optimization problem is then the well established nonlinear programming problem (Section A). Symbolically it is expressed as:

maximize	$f(\mathbf{u})$
subject to	$y(\mathbf{u})\ \alpha\ \mathbf{b}$
where	**u** is the control parameters
	f is the objective function
	y is the constraint parameters
	α is the parameters relation $\leq$, = , or $\geq$
	b is the constraint parameter limits.

Other than obvious format differences this is identical to the optimization problem previously established.

2. Algorithm Macrologic

As mentioned above, POST uses the accelerated projected gradient algorithm as the basic targeting/optimization technique. The program also contains backup single penalty function methods that use steepest descent or conjugate gradients in conjunction with PGA.

The accelerated projected gradient algorithm is based on five intuitive working principles:

1. One-Dimensional Search. Using cost (objective) and constraint function gradient information, a direction of search is established. Then a one-dimensional minimization is performed in this direction on an appropriate function. This technique replaces a difficult multidimensional problem with a sequence of simple one dimensional minimizations.
2. Linearized Constraint Correction. This correction assumes that the current vector of control parameters is outside the feasible region. This scheme then approximates the contours of constant constraints as uniformly spaced parallel hyperplanes based on their respective gradients and values for the current control parameter vector. Using this approximation the smallest correction to the control parameters that would satisfy all active constraints is computed. One dimensional minimization of the sum of the squares of the constraint errors is then performed along the direction of this correction to obtain the next iterate of control parameters.
3. Gradient Projection. Once a feasible vector of control parameters is obtained, the negative gradient is resolved into two components; one parallel to and one normal to the hyperplane tangent to the boundary to the feasible region at the current point. A minimization is then performed along the direction of the parallel negative gradient component to obtain the next control parameter iterate. The function to be

minimized in this one dimensional search is the Estimated Net Cost Function (Item 4 below). The "cost function" and "objective function" are interchangeable terms.

4. Estimated Net Cost Function. Since the constraints are usually nonlinear, the tangent plane only coincides with the boundary of the feasible region at the point of tangency; therefore, a search along the component of the gradient lying in the tangent plane will probably terminate at a point external to the feasible region. The real object of the search should not be to find the minimum value of the objective (cost) function in the search direction, but to find a unique point along the search direction that, when corrected back to the feasible region, yields an improved value of the objective function. This point is approximately determined by minimizing along the parallel component of the gradient the objective function minus an estimate of the deterioration of the objective function performed by occasional corrections back to the feasible region. The estimate is based on the linearized constraint-correction formulas (referred to in Item 2, above).
5. Gradient Acceleration. It has previously been noted that the convergence of unconstrained gradient algorithms can be improved by using gradient information from estimations of the inverse of the Hessian matrix of quadratic form that approximates the objective function. It was stated in Section B that an objective function of m control parameters can be converged to an optimum solution in m iterations using a Hessian-inverse estimating accelerated gradient scheme. To similarly accelerate the PGA for constrained problems, it is assumed that the objective function is a quadratic in $m-q$ variables over the constraint boundary (where q is the number of active constraints defining the boundary). Thus convergence should be accelerated to $m-q$ iterations after the set of active constraints that determines the feasible region stabilizes. [Ref. 21:pp. 49-50]

For some of the special cases of the general nonlinear programming problem, the accelerated projected gradient algorithm degenerates into the appropriate special purpose algorithm. For example, if the problem is unconstrained, PGA becomes a Davidon

deflected gradient procedure (Section B, Part 3). If the problem has more active constraints than controls, the PGA reduces to the standard Gauss' least squares procedure for minimizing constraint violation. If the number of controls equals the number of constraints, the PGA becomes the well-known Newton-Raphson procedure for solving systems of nonlinear equations.

A summary of the logic of the accelerated projected gradient algorithm is presented in Figure 8. If the initial guess violates any constraints, then the algorithm attempts to satisfy all the constraints by taking constraint restoration steps. Once a feasible control parameter vector has been found, the algorithm generates a sequence of iteration pairs. Each pair consists of an optimization step followed by a constraint step. If the initial control parameter estimate is not feasible, a steadily improving sequence of constraint-correction steps is taken until a feasible solution is found. Additionally, the optimization step is omitted after any constraint-correction step which fails to yield a feasible control parameter vector. [Refs. 20,21]

The algorithm has two stopping conditions. First, the search is stopped if both the change in the objective function value and the length of the change in the control parameter vector between two successive optimization steps falls below the input tolerances. Second, the procedure is terminated if the maximum permissible number of iterations specified at input is exceeded.

The next step is to translate the aeroassisted problem into POST and compare how the various maneuvers perform in this simulation.

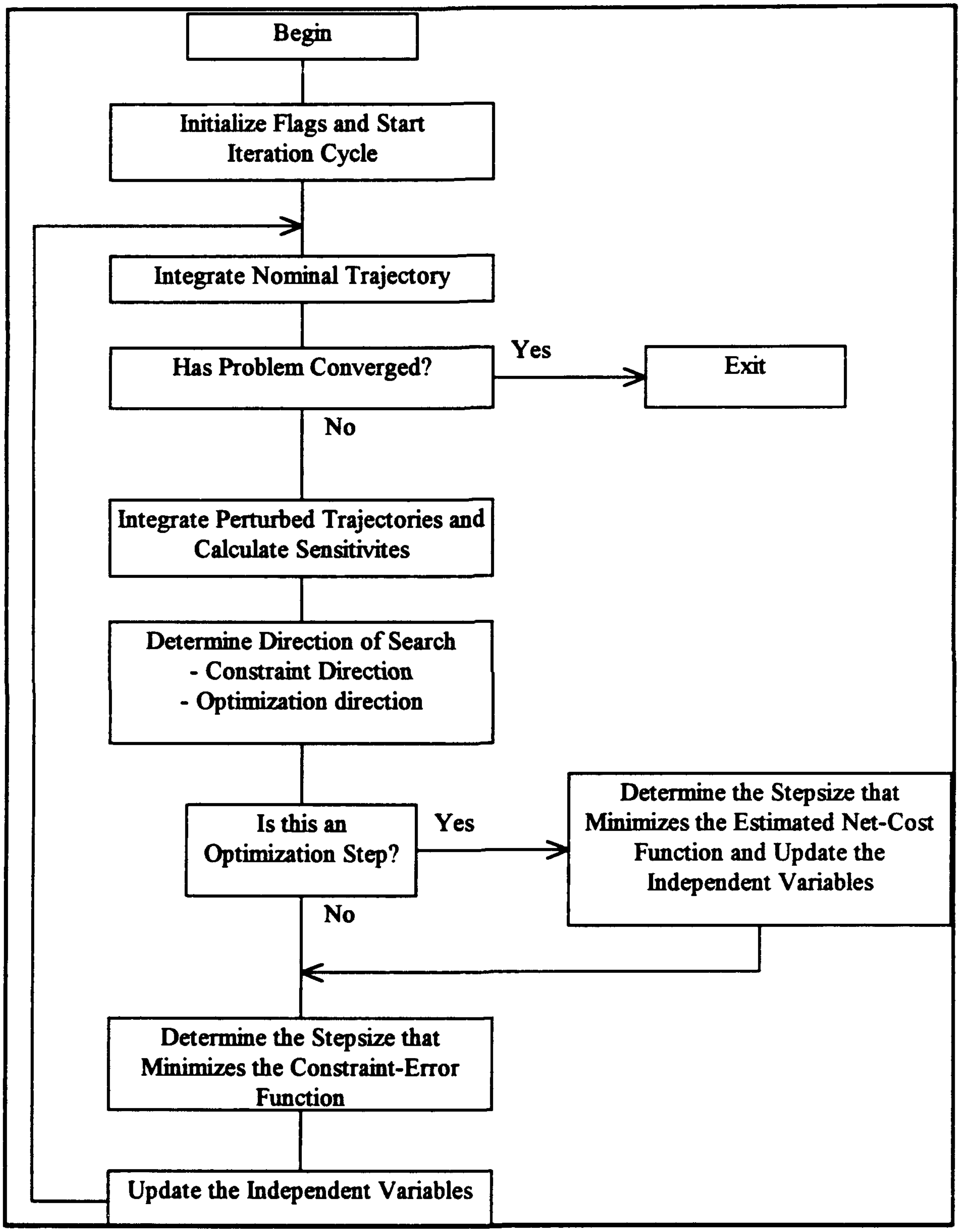

Figure 8. Macrologic of Projected Gradient Algorithm

IV. DEVELOPMENT OF SIMULATION

The problem now must be translated into simulations on NASA's Program to Optimize Simulated Trajectories (POST). The output of this program should provide results that show which maneuver performs the best, given a set of distinguishing criteria. A numerical analysis between the types of maneuvers proposed, the inclination change they achieve and their ability to control the heating rate should provide the standards for comparison of these maneuvers.

An overview of the setup of POST, how it simulates a trajectory, and the details of the vehicle model, atmospheric model, and aerodynamic/aeroheating model are examined here.

A. POST

Although a brief overview of POST is included here, the details of working with the program can be found in Appendix A - A Primer for POST. This appendix includes the fine points of setting up and running an input file on the Naval Postgraduate School's computer facilities. It also summarizes References 20 and 22, the POST Formulation and Utilization Manuals. Sample input and output files are found in Appendices B and C, where an example of the aeroassisted maneuver's data decks are listed.

1. Overview

POST is a general purpose FORTRAN program for simulating and optimizing point mass trajectories of aerospace vehicles. The program can be used to solve a wide variety of performance and mission analysis problems for atmospheric and orbital vehicles.

One of the key features of POST is an easy to use namelist-type input procedure. This feature significantly reduces input file setup time for studies that require the normal large amount of input data. In addition, the general applicability of POST is further enhanced by a general purpose discrete parameter targeting/optimization capability. This

capability can be used to solve a broad spectrum of problems related to the performance characteristics of aerospace vehicles. [Ref. 20:p 1]

The basic simulation flexibility is achieved by decomposing the trajectory into a logical sequence of simulation segments. These trajectory segments, referred to as phases or events, enable the trajectory analyst to model both the physical and the non-physical aspects of the simulation accurately and efficiently. By segmenting the mission into phases, each phase can be modeled and simulated in a manner most appropriate to that particular flight regime.

Every computational routine in the program can be categorized according to five basic functional elements. These elements are the planet module, the vehicle module, the trajectory simulation module, and the targeting/optimization module. The planet module is composed of an oblate spheroid model, a gravitational model, an atmosphere model, and a winds model. These models define the environment in which the vehicle operates. The vehicle model is comprised of the mass properties, propulsion, aerodynamic, aeroheating, and steering (guidance) models. These models define the basic vehicle simulation characteristics. The trajectory simulation module consists of the event-sequencing module that controls the program cycling, the table interpolation routine, and several standard numerical integration techniques. These models are used in numerically solving the translational and rotational equations of motion. The targeting/optimization module provides a general discrete parameter iteration capability. The user selects the optimization variable, the dependent variable, and the independent variables from the list of more than 400 program variables. An accelerated projected gradient algorithm is used as the basic optimization technique. This algorithm is a combination of Rosen's projection method for nonlinear programming and Davidon's variable metric method for unconstrained optimization. In the targeting mode, the minimum norm algorithm is used to satisfy the trajectory constraints. The cost and constraint gradients required by these algorithms are computed as first differences calculated from perturbed trajectories. To reduce the computer time in calculating numerical sensitivities, only that portion of the

trajectory influenced by any particular independent variable is reintegrated on the perturbed trajectories. This feature saves a significant amount of computational time when targeting and optimization is performed. [Ref. 20:pp. 1-5]

The basic program macrologic is outlined in Figure 9, which illustrates the linkage between the simulation and targeting/optimization structure of the program [Ref. 20:p. 5].

2. Trajectory Module

The following sections present the equations used in the trajectory simulation subroutines. These equations summarize the principal computations performed by the program and motivate many of the program input procedures.

a. Events/Phases

Simulation data are input according to phase, where the phases are defined by a user-specified sequence of events. The simulation equations are then solved sequentially by phase. Therefore the user is required to input a sequence of trajectory segments that define the problem being simulated from beginning to end. These trajectory segments, or phases, are defined by two events: a beginning event and an ending event. An event is an interruption of the trajectory simulation that occurs when a user specified variable reaches a user specified value. An event must be created whenever the user wishes to change any input data for the problem or to cause any change in the method of simulating the problem. The program requires that each problem have a minimum of two events - an initial event and a final event.

The time-to-go-to-event model determines when the events occur during a trajectory simulation. Basically, this model checks the value of the criteria being monitored at each integration step. If none of the criterion values has bracketed the cutoff value, then another integration step is taken

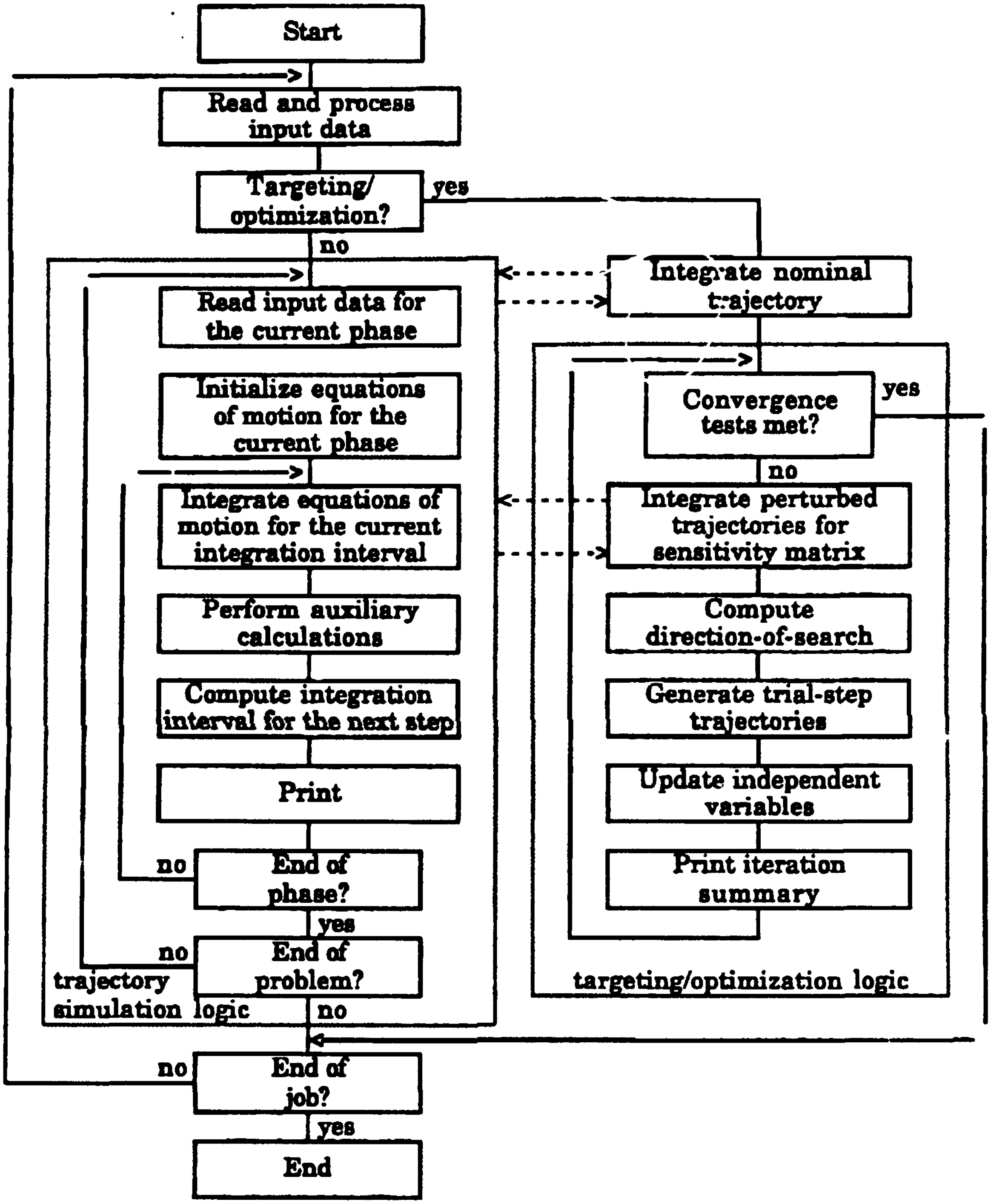

Figure 9. Program Macrologic

b. Translational Equations

The translational equations of motion are solved in the planet-centered inertial coordinate system. These equations are

$$d\underline{r}_I / dt = \underline{V}_I$$

$$d\underline{V}_I / dt = \mathbb{IB}^{-1}\left(\underline{A}_{TB} + \underline{A}_{AB}\right) + \underline{G}_I$$

where r_I and V_I are the position and velocity in inertial coordinates, $\underline{A}_{TB}$ is the thrust acceleration in the body frame, $\underline{A}_{AB}$ is the aerodynamic acceleration in the body frame, and $\underline{G}_I$ is the gravitational acceleration in the Earth Centered Inertial frame (IB is the required coordinate transformation matrix). There are five options for initializing the velocity vector and two options for initializing the position vector. These include inertial position components, earth-relative position, inertial velocity components. inertial local horizontal, earth relative local horizontal, atmospheric-relative local horizontal, and orbital parameters

c. Integration Methods

The number of integrals computed during any particular phase is determined by options requested by the user. At a minimum, the translational equations of motion are integrated to give the position and velocity of the center of mass of the vehicle. POST's main general purpose integration method is the standard fourth order Runge-Kutta method. The calculations for this integration method are based on the formula

$$y_{n+1} = y_n + \sum_{i=1}^{s} b_i\, k_i$$

where

$$k_i = \nabla f\left(x_n + c_1 h,\ y_n + \sum_{j=1}^{s} a_{ij}\ k_j\right),\ i = 1,2,\ldots,s$$

These formulas are represented by the array

$$
\begin{array}{c|cccc}
c_1 & a_{11} & a_{12} & \cdots & a_{1s} \\
c_2 & a_{21} & a_{22} & \cdots & a_{2s} \\
\cdot & \cdot & \cdot & & \cdot \\
\cdot & \cdot & \cdot & & \cdot \\
\cdot & \cdot & \cdot & & \cdot \\
c_s & a_{s1} & a_{s2} & \cdots & a_{ss} \\
\hline
 & b_1 & b_2 & \cdots & b_s
\end{array}
$$

With the coefficients for the fourth order Runge-Kutta given below.

$$
\begin{array}{c|cccc}
0 & \text{--} & & & \\
1/2 & 1/2 & \text{--} & & \\
1/2 & 0 & 1/2 & \text{--} & \\
1 & 0 & 0 & 1 & \text{--} \\
\hline
 & 1/6 & 1/3 & 1/3 & 1/6
\end{array}
$$

Further details on the numerical integration techniques used are available in the POST Formulation Manual [Ref. 20].

B. MODELS

1. Flight Vehicle

As mentioned in Chapter I, early investigators of synergetic maneuvers came to two main conclusions: first, the lifting body should operate at $(L/D)_{max}$, and second, the L/D should be greater than one to be superior to the all propulsive maneuver [Ref. 1:p. 5]. The emphasis on $(L/D)_{max}$ led to the selection of a vehicle which operates at an $(L/D)_{max}$ of approximately 1.8, the Entry Research Vehicle (ERV). Flight vehicles which have been designed and have data available provide a sense of reality to the analysis, where as an imaginary flight vehicle and data might skew the study [Ref. 15:p. 8].

The Entry Research Vehicle was designed with the idea of investigating and exploiting maneuvers involving long downrange, wide crossrange, and synergetic plane

changes [Ref. 23]. The vehicle is 7.62 m long and has a wing span of only 3.96 m, allowing the vehicle to be launched from the cargo bay of the space shuttle. Aerodynamic surface area (S) is 16.48 m^2 with the slenderness ratio of the fuselage approximately 0.167. Figure 10 shows a three-view sketch of the ERV. Three Marquardt R-40-B rocket motors make up the propulsion system, providing a total of 14679 Newtons of thrust at a specific impulse (I_{SP}) of 295 seconds. Separation weight from the shuttle is 5443 kg with up to 50% of that made up of fuel. [Ref. 23, 24]

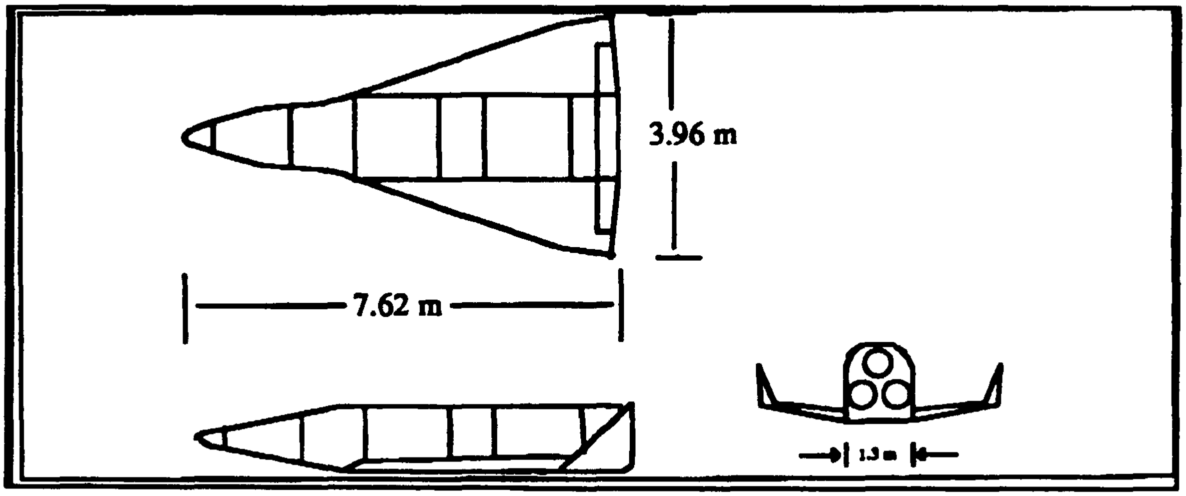

Figure 10. Diagram of Entry Research Vehicle [Ref. 15:p. 9]

For the purposes of modeling within POST, the aerodynamic data were approximated by a table of data points, with POST's interpolation routines allowed to linear interpolate between values (Figures 11 and 12, data equations listed below each figure). Wind-tunnel data for the ERV is available and included lift and drag data up to Mach 10. These data was used for flight velocities from 6.0 km/sec to 8.5 km/sec. Although these velocities correspond to Mach numbers around Mach 20 at the maneuvering altitude, the data from Mach 10 can be realistically applied because of the limiting characteristics exhibited by the bow shock and pressure distribution over the lifting body [Ref. 16:pp. 387-388]. From the L/D curve (Figure 13), it can be seen that $(L/D)_{max}$ occurs at approximately 11.9 degrees with a value of 1.84.

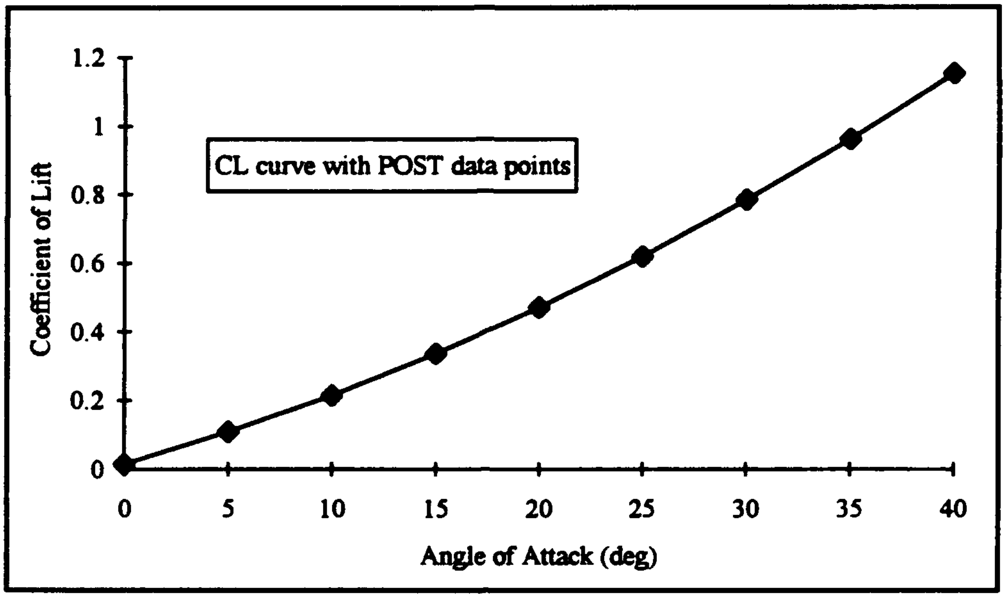

Figure 11. Coefficient of Lift vs. Angle of Attack

$$C_L = 0.924*\alpha^2 + 0.985*\alpha + 0.015$$

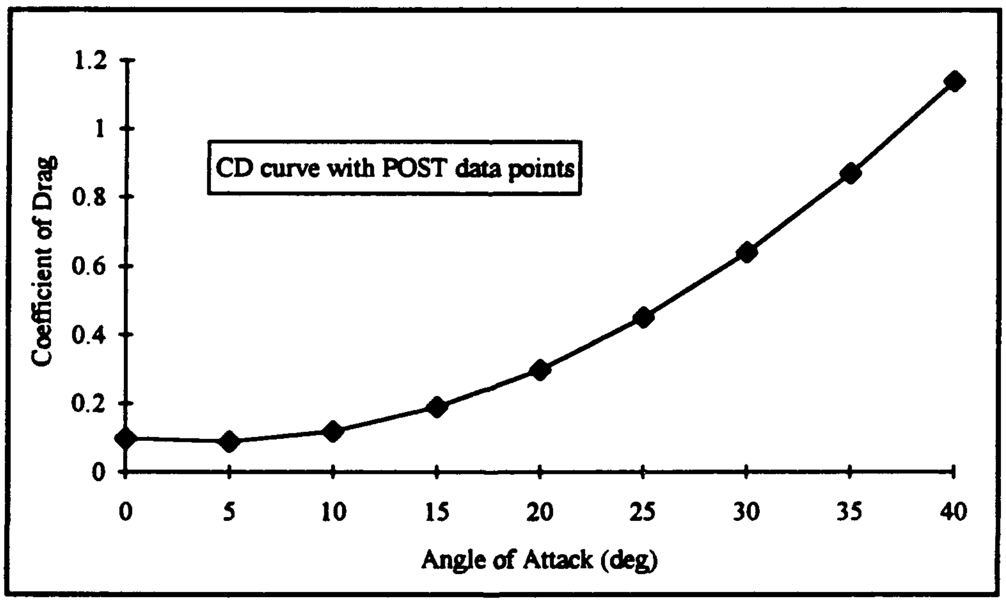

Figure 12. Coefficient of Drag vs. Angle of Attack

$$C_D = 2.619*\alpha^2 - 0.334*\alpha + 0.097$$

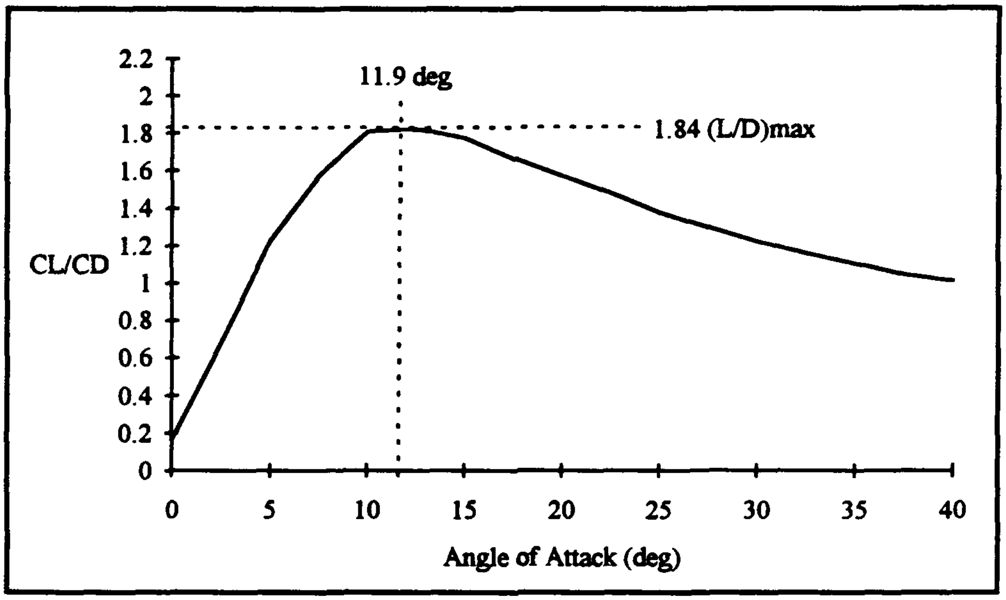

Figure 13. C_L/C_D vs. Angle of Attack

2. Atmosphere

The atmosphere model is a portion of the planet module in POST. This model computes atmospheric pressure, density, temperature, and speed of sound. POST has several built-in polynomial models available including the 1962 U. S. Standard Atmosphere, 1963 Patrick AFB Atmosphere, 1971 Vandenberg AFB Atmosphere, and the 1976 U. S. Standard Atmosphere Model. [Ref. 20]

The model chosen for this simulation was the 1976 U. S. Standard, which is an idealized steady-state representation of the Earth's atmosphere from the surface to 1000 km, as it assumed to exist in periods of moderate solar activity. The model is usually represented as a function of geopotential altitude. [Ref. 25]

3. Aerodynamics/Aeroheating

The aerodynamic lift and drag coefficients input into POST are transformed to axial and normal force coefficients as follows:

$$\begin{pmatrix} C_A \\ C_N \end{pmatrix} = \begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} C_D \\ C_L \end{pmatrix}$$

where α is the angle of attack, C_A is the axial direction aerodynamic coefficient, and C_N is the normal direction coefficient. Each aerodynamic coefficient is obtained by interpolating the values in the table. These can be tables of one, two, or three variables; the ERV coefficient data above is based solely on angle of attack and a monovariant table would be us?d.

The Mach number and dynamic pressure are given by:

$$M = {V_A}/{C_S}$$

$$q = \frac{1}{2}\rho V_A^2$$

where ρ is the atmospheric density, V_A is the magnitude of the velocity of the vehicle with respect to the atmosphere, and C_S is the speed of sound. These atmospheric parameters are obtained from the atmosphere model that is chosen and usually are a function of the altitude above the planet's surface.

The axial and normal aerodynamic forces in the body frame are obtained from

$$\underline{F}_{AB} = qS\begin{pmatrix} -C_A \\ -C_N \end{pmatrix}$$

where q is the dynamic pressure and S the aerodynamic reference area. The resulting accelerations on the body are then obtained from

$$\underline{A}_{AB} = \frac{1}{m}\underline{F}_{AB}.$$

POST provides a wide variety of aeroheating calculations. The general heat rate equation used in this simulation was Chapman's equation, where the heat rate (in BTU/ft^2 sec) is given by

$$dQ/dt = \frac{17600}{\sqrt{R_N}}\left(\frac{\rho}{\rho_{SL}}\right)^{1/2}\left(\frac{V_A}{26000}\right)^{3.15}$$

where R_N is the nose radius (in ft), ρ the atmospheric density, and V_A the vehicle's velocity magnitude (in ft/sec) with respect to the atmosphere. This formula is then converted to metric units by

$$1 \text{ BTU/ft}^2 \text{ sec} = 11{,}356.53 \text{ W/m}^2.$$

C. TRAJECTORY SIMULATION

The first step in performing the simulation is to define the problem as a series of steps. The first event defines the initial conditions of the environment and the vehicle. Each event after that must include the conditions at which it is to occur, i.e., the name of the condition (variable) and its value. Control variables and target variables will be active in different events and should be specified. The optimization variable's event number also will have to be listed. It also is important to note whether the targets are inequality or equality constraints. There must be more controls than targets for any optimization to occur.

The aeroassisted maneuver depicted in Figure 14 can be broken down into ten events. These events are defined as 1) initial orbit, 2) fire retrorocket to lower perigee into atmosphere, 3) turn off the rocket, 4) enter the atmosphere, 5) encounter heat rate constraint (if active), 6) begin boost out of atmosphere, 7) shut off engines, 8)exit atmosphere, 9) reach orbit altitude and recircularize, 10) end simulation. The details of each event will be covered for each of the proposed maneuvers. Similarities and differences are emphasized as well as some of the peculiarities of implementing the control strategies in POST.

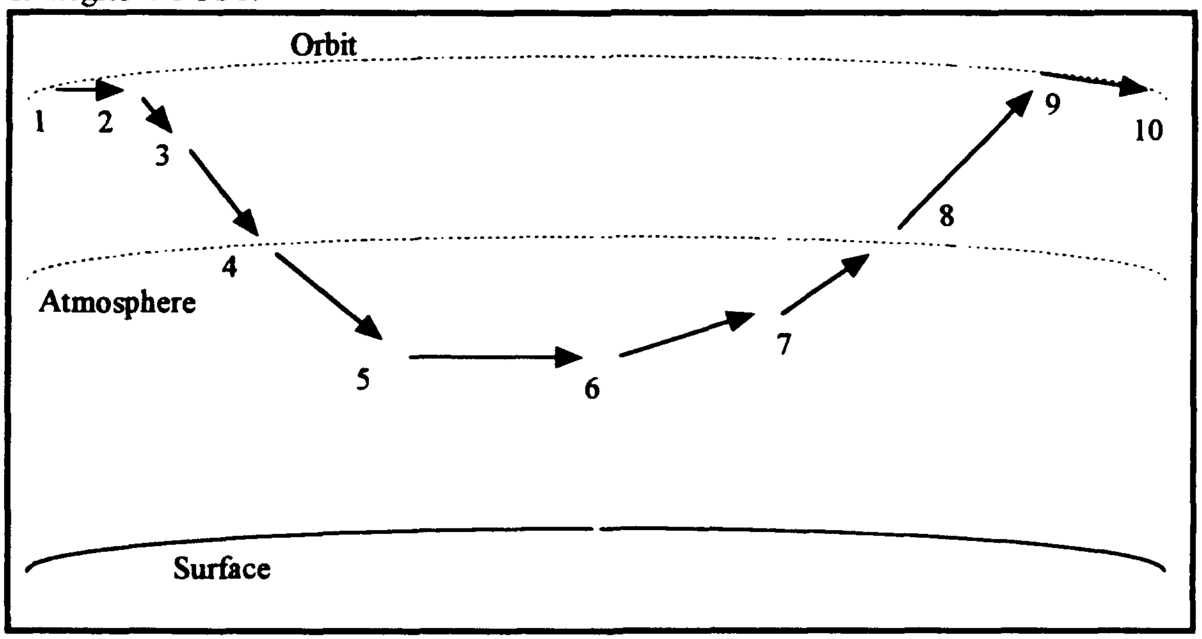

Figure 14. Trajectory Definition

1. Event One

The initial conditions for this problem are input in terms of the orbital elements. A circular orbit at 300 km altitude with an inclination of zero degrees (0°) is specified. This approximates a low earth equatorial orbit. For the flight vehicle, the total weight is specified (approximately 50,000 Newtons) and the fuel weight for this particular run (20-40% of vehicle weight). Other vehicle characteristics, surface area and specific impulse, for example, are included here. For this trajectory, the integration stepsize (one second) and method (Runge-Kutta), plane model (spherical rotating earth) and guidance type (aerodynamic angles) are specified.

2. Event Two

The program has commenced. Five seconds after the initial conditions, the vehicle is flipped over and the engines are fired. The five seconds is chosen arbitrarily, a small number limits the amount of numerical integration steps from the initial position. The vehicle is flipped over by setting the angle of attack to 180 degrees. This unorthodox technique is equivalent to a retrorocket firing which forces the vehicle to slow down, lowering the perigee altitude. By using the main engines in this manner for the firing, the deorbit fuel is included in the total propellant weight without specifying a complex propulsion system. POST does allow the user to specify the engine location, characteristics and firing directions, as well as a propellant feed system, but this level of complexity is not required for analyzing the aeroassisted maneuver. This "retrorocket" firing changes the vehicles speed and the circular orbit becomes elliptical, eventually lowering the perigee into the atmosphere. This rocket could be fired at an angle to cause a slight inclination change in conjunction with the deorbit. This control option was not included in the final comparison, since the amount of inclination change is nearly the same (although dependent on total fuel) for each maneuver.

3. Event Three

When the perigee altitude has reached 50 km, the engines are shut off and the vehicle coasts down to the atmosphere. The choice of 50 km is in the range of acceptable values of 40 km to 75 km. These values were determined from several single pass runs. Altitudes over 75 km caused the simulation to last a prohibitively long time, with numerous integration steps. The angle at which it entered the atmosphere was also not steep enough and the naturally lifting vehicle had a tendency to "skip" or fly back out of the atmosphere. Perigee altitudes below 40 km created extreme heating rates and the vehicle did not have enough control authority (the lift vector plus the throttle power) to "pull out" of a very steep entry angle.

4. Event Four

When the altitude of the vehicle has reached 120 km, the atmosphere is activated. As previously mentioned, the 1976 U. S. Standard Atmosphere is used in this simulation. The aeroheating equations are also calculated now. Tables of aerodynamic coefficients are input for this phase, and the guidance option of aerodynamic angles (aoa, bank, sideslip) is activated. Control variables for this phase are the angle of attack (α) and the bank angle (δ). These aero angles can be calculated as polynomials of up to third order, however, just the zero-order constants are used here. There is no thrust during this, the "glide" portion of the trajectory.

5. Event Five

Event five activates the heating rate controls, if they are to be used. This event start is based on the time duration of the previous phase. This time is set by first performing the simulation run for a specific fuel weight with the aeroglide (glide-bang profile) maneuver. The heating rate encountered during this unconstrained pass is then examined and two separate heating rate levels were chosen. These values were $1.41*10^6$ W/m^2 (approximately 125 BTU/ft^2*sec) and $9.6*10^5$ W/m^2 (about 85 BTU/ft^2*sec). The time these values were achieved during the unconstrained maneuver was noted, and these

times were the values chosen for beginning the heat rate control event for aerocruise and aerobang.

In aeroglide, this event is not included, instead the next event (see Event Six) will be the boost phase ("bang") back into orbit. However, the implementation of these two heating rate control schemes in POST are discussed next.

a. Aerocruise

The presentation of the control laws for aerocruise were given in Chapter II. The equations for steady-state cruise are shown below:

$$T = \frac{D}{cos\alpha}$$

$$cos\delta = \frac{m\left(g - \frac{v^2}{r}\right)}{L + T sin\alpha}$$

$$\alpha = \text{ free variable}$$

The angle of attack is a free variable here, so it is used as a control variable in POST. To produce a more accurate picture of the control history of an optimal trajectory, both α and the rate of change of α are used, i.e., a first order linear approximation.

Since drag is computed by POST at each integration step and α is a control variable, a bivariant table for thrust is developed. "No extrapolation" flags were required to ensure that the thrust requested by the cruise maneuver did not exceed that available ($T \leq T_{max}$).

To develop the bank angle control, a more complex procedure had to be followed. Since bivariant tables are the quickest to generate, they were used in combination to form the bank angle table. It took several tables to form the final table, as outlined below:

$$\mathrm{x1}(\mathrm{v},\mathrm{r}) = \left(g - \frac{v^2}{r}\right) = \left(\frac{\mu}{r^2} - \frac{v^2}{r}\right)$$

$$\mathrm{x2}(\mathrm{T},\alpha) = T\,sin(\alpha)$$

$$\mathrm{x3}(\mathrm{m},\mathrm{x1}) = m * x1$$

$$\mathrm{x4}(\mathrm{L},\mathrm{x2}) = L + x2$$

$$\delta(\mathrm{x3},\mathrm{x4}) = cos^{-1}(x3 / x4)$$

This is not the most straight-forward method of implementing a control program, and is one of the drawbacks of POST.

The other problem encountered when running the simulation was that the flight path angle, γ, was not zero. This is essential to making the steady-state aerocruise steady-state. By examining the equations of motion (Chapter II) it can be observed that as long as this angle is small ($|\gamma| \leq 1.0°$), the assumption of $\gamma = 0°$ is a close approximation. Since the flight path angle is usually less than half a degree ($|\gamma| \leq 0.5°$) when the heat control begins, POST was instructed to ensure that the *change* in the flight path angle ($d\gamma / dt$) was zero. Hence a pseudo-steady-state aerocruise is performed. This did not appear to affect the outcome of the program detrimentally, and actually improved the results obtained from aerocruise prior to modifying the flight path angle parameter. The new results obtained were closer to those anticipated by prior researchers (Chapter V).

b. Aerobang

The control scheme for the aerobang maneuver is shown below:

$$T = T_{MAX}$$

$$T cos\alpha \; - \; D(\alpha) = m \; sin\gamma \left(g + v^2\xi\right) \;\; \text{yields } \alpha$$

$$\delta = \text{free variable}$$

The bank angle is a control variable and the rate of change of this angle is also used as a control parameter: another first order approximation. Thrust is also easily

directed in this control scheme. The problem comes when trying to implement the equation for α into POST.

In order to solve the implicit function for α, several approximations have to be made along the way. The approach used was to develop a second order Taylor's series for the cosine function and combine it with the equation for drag, which includes a second order equation for α as well. Combining these functions into a quadratic polynomial in α, the roots of the equation should yield the angle of attack to be flown to control the heating rate.

Beginning with the Taylor polynomial for a cosine function

$$\cos x \approx 1 - x^2/2 = T_0(x)$$

where x is in radians, and will serve as a generic "α." This is for the function evaluated around the point $x = 0$. If the function is evaluated around $x = 12.0° = 0.20944$ rad, the polynomial expansion becomes

$$\cos x \approx 1.0024 - 0.00305\,x - x^2/2.0447 = T_{12}(x)$$

which is quite similar. The angle of 12° was chosen since this is near $(L/D)_{max}$. Figure 15 compares these curves in the area between 0° and 50°, although α should be less than 40° throughout the maneuver. At an extreme of 40°, the cosine is 0.766, the first approximation (T_0) is 0.756 (98.7 %) and the second approximation (T_{12}) is 0.760 (99.2%). Overall, quite an accurate approximation and the second polynomial expansion will be used to eventually find α.

The equation for drag is a standard,

$$D = \frac{1}{2}\rho\, V_A^2 S\, C_D = \frac{1}{2}\rho\, V_A^2 S\left(2.6189\alpha^2 - 0.3340\alpha + 0.0974\right)$$

where ρ is the atmospheric density, V_A is the vehicle velocity relative to the atmosphere, S is the surface area of the vehicle, and C_D is the coefficient of drag equation. This equation, in concert with the cosine quadratic approximation, will be used to solve for the angle of attack control profile during this event.

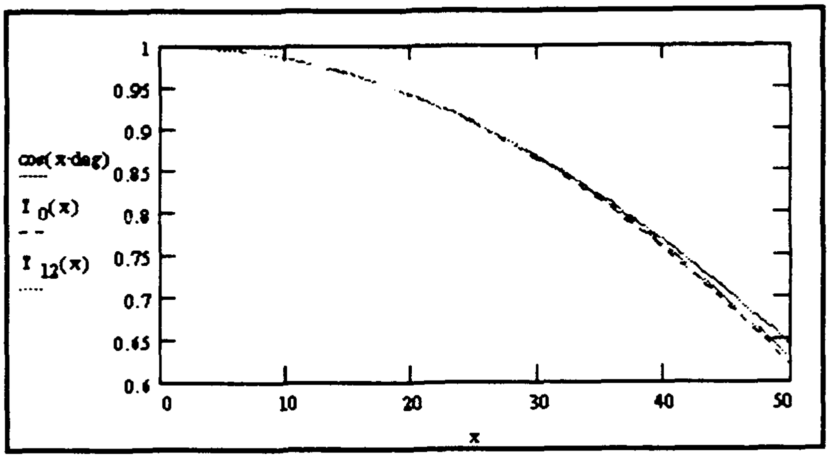

Figure 15. Comparison of Taylor Approximation

To form the final α table is another convoluted process, where bivariant tables are combined to lead to the final solution. [Note that α is in radians.]

$$x1(v,r) = (g - v^2\xi) = \left(\frac{\mu}{r^2} - v^2\xi\right)$$

$$x2(m,\gamma) = m\sin(\gamma)$$

$$x3(x1,x2) = x1 * x2$$

$$x4(\rho,v) = \frac{1}{2}\rho v^2 S$$

and

$$T_{max}(1.0024 - 0.00305\,\alpha - \alpha^2/2.0447) -$$
$$x4\,(2.6189\alpha^2 - 0.3340\alpha + 0.0974) = x3$$

so that

$$\alpha^2(-T_{max}/2.0447 - x4*2.6189) +$$
$$\alpha\,(-T_{max}*0.00305 + x4*0.3340) +$$
$$(T_{max}*1.0024 - x4*0.0974 - x3) = 0$$

which is the quadratic equation in α (x3, x4). This equation is translated to the final input table for angle of attack. Thus the aerobang heat rate control scheme is in place.

6. Event Six

This event begins the "unconstrained" boost back into orbit (there are no active heat rate constraints). The criterion to begin this event is based on the time duration of

the previous event, which is dependent on the type of maneuver. For aeroglide, the time duration is a free variable, which POST is allowed to vary based on forming the optimal trajectory. For aerocruise and aeroglide, the time duration is found by examining the unconstrained case and determining the times that the heat rate control is required. This is used as the nominal input to POST, with the heat rate examined after the run and the time adjusted to ensure that the control scheme is in place whenever the heat rate goes above the selected higher or lower limit.

Control variables during this phase are the rates of change of the angles of attack and bank (i.e., $d\alpha/dt$, $d\delta/dt$). Thrust is at the maximum setting.

7. Event Seven

This event turns off the engines after a certain burn time. This time is estimated by a single pass run that determines the burn time to ensure sufficient apogee height. With this time input to the nominal trajectory, the burn time also becomes a control variable. The vehicle is usually still in the atmosphere during this phase, but this event is specified as a "roving event" in case the vehicle has exited the atmosphere. A roving event allows this phase to "float" within the specified trajectory, so that it can occur after another event. The rates of change of the angles of attack and bank are again control variables.

8. Event Eight

This event is reached when the vehicle reaches 120 km altitude. The atmosphere and aeroheating calculations are turned off. This is a roving event similar to the previous one, which allows for a realistic trajectory. All guidance options are set to inertial aerodynamic steering, with all angles set to zero. This allows for a comparison of the effective maneuvers within the atmosphere, since the differences if exo-atmospheric maneuvers were included in the problem would make it too complex for this analysis.

9. Event Nine

This event commences when the altitude of 300 km is reached by the vehicle. A propulsion maneuver is accomplished that circularizes the orbit at this altitude. This is

approximately a fixed amount independent of the maneuver, but appropriate flags are set to ensure that this maneuver uses the same fuel supply (it can be set to a separate system). When the optimal maneuver is accomplished, this fuel burn should use the last of the fuel specified for this run. In reality, this would take several seconds to accomplish, however, POST's versatility allows for this to be accomplished instantaneously.

10. Event Ten

Five seconds after the previous event begins, the final event starts. This event merely shuts down the program by setting the appropriate flags. Now that the program is finished, it should be pointed out that POST allows for several program interruptions, to stop a wayward input trajectory. For the case examined here, a maximum time setting of 10,000 seconds and a minimum altitude of 40 km were entered. This stopped the program if the nominal trajectory was not going to work. Table 1 summarizes the POST variables throughout this problem.

TABLE 1. SUMMARY OF POST TRAJECTORY EVENTS

Event No.	Criterion Variable & Value	Control Variables	Target Variables	Optimization
1	initial	conditions		
2	time duration = 5 sec			
3	perigee alt = 50 km			
4	altitude = 120 km	angle of attack (α) bank angle (δ)		
5*1	time duration*2	α , $d\alpha/dt$*3 δ, $d\delta/dt$*4	$d\gamma/dt = 0$*3	
6	time duration*5	α , $d\alpha/dt$, δ, $d\delta/dt$*6 $d\alpha/dt$, $d\delta/dt$*3,4		
7	time duration ≈ 75 sec	$d\alpha/dt$, $d\delta/dt$		
8	altitude = 120 km			
9	altitude = 300 km		alt = 300 km	
10	time duration = 5 sec		wt prop = 0	inclination

*1 Event 5 skipped for aeroglide.

*2 Duration of glide dependent on heat rate encountered, varies 300 - 525 sec

*3 Aerocruise

*4 Aerobang

*5 Duration of heating rate control phase varies with fuel, 75 - 200 sec

*6 Aeroglide

V. RESULTS AND ANALYSIS

The different aeroassisted maneuver profiles were translated into simulations on NASA's Program to Optimize Simulated Trajectories (POST) by the method discussed in Chapter IV. The goal throughout the process is to use the controls (aerodynamic angles) to maximize the inclination change while using all the given fuel and returning to circular orbit. The method of determining the final input trajectory is outlined below, along with examples of the control profiles and significant results. An analytical and numerical comparison is made between the types of maneuvers proposed. A recommended "best" maneuver is suggested for a given fuel amount and desired inclination change.

A. OVERALL METHOD OF SOLUTION

The first step was to determine the nominal input control trajectory. As mentioned previously, POST is sensitive to these inputs and can return a "Problem solved, trajectory optimized" message with a different solution value for each different input. It could be said that POST provides the optimal solution for an input, but not all inputs will produce the overall optimal result. In order to confirm that POST was very close to a "global" optimum, it was decided that if minor deviations to the input controls produced consistent values of the performance index, then this would be considered the optimal control history. Normally, several runs were required to determine a good nominal trajectory input.

The glide-bang solution for a particular fuel weight was found first. Consistent results were found for the control history and inclination change. The heating rate curve was examined, and break times for the cruise and constrained bang controls were chosen. These times were set into the input files, and a repeat of the iterative process to finding a consistent optimal solution was initiated for the aerocruise and the aerobang maneuvers. After consistent results were found for these profiles, the fuel weights were changed and this method of solution started again.

B. GLIDE - BANG

1. Input

A typical aeroglide profile was developed that did not include any optimization variables. The reason for this was to develop a good knowledge base of what the aerospace vehicle went through during its run in the atmosphere. Several runs at different angles of attack and bank were conducted to generate this baseline. After these runs were performed, the break times for particular events and the nominal values for the controls were selected.

For a specific fuel weight, it would take approximately five non-optimized runs to get a good idea where the nominal trajectory should begin. The optimization and targeting feature would be activated and 10 to 15 more runs would have to be conducted to ensure a near-global optimal solution was found. Part of the reason for these extra runs was the targeting feature of POST. It could take five to nine runs to target the final altitude and final fuel weight, then the optimization of the inclination change could begin. POST was set to a maximum of 50 iterations per run, and the runs were conducted on a SPARC 10 with 128 Mb of RAM. A typical run took about 15 minutes to complete, and usually two days were required to find a final optimal solution.

2. Controls

Figure 16 outlines the "optimized" control parameters for the basic glide-bang maneuver for a fuel percentage of 20% (approximately 10,000 Newtons on the 50,000 Newton ERV). Both the angles of attack and bank are constants during the initial glide phase, then the rates of change of these angles are adjusted. This provides a more practical idea of the maneuvering that would be required, as "instantaneous" changes of these angles will probably not occur in reality. The thrust profile is also shown in the figure, although it is not a control variable. The break times in the control history were selected by POST and are where the thrust is turned on and off. As previously mentioned, there is no heat constraint during this option, thus this should produce the maximum inclination change of any of the profiles.

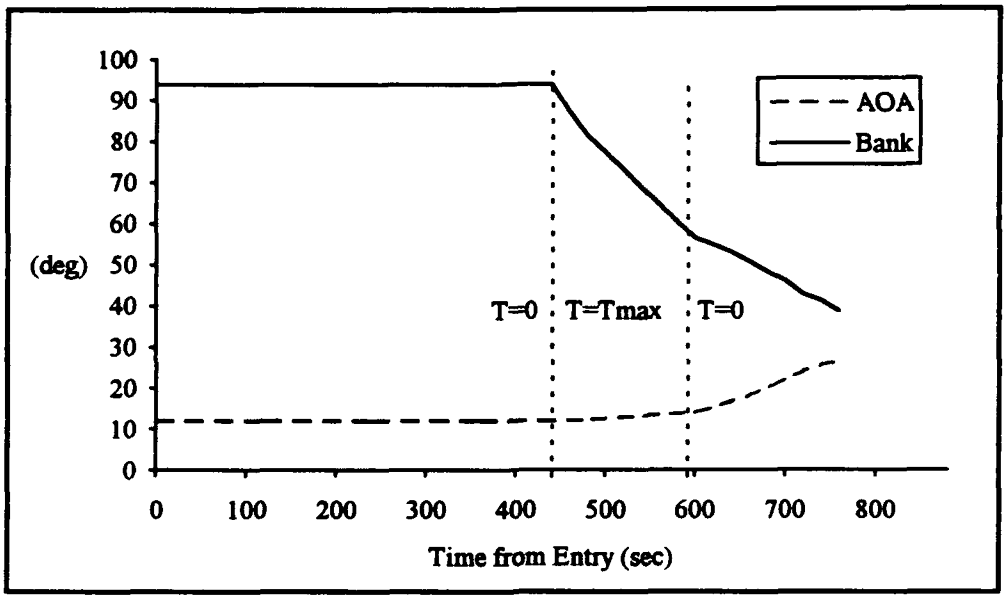

Figure 16. Control History for 20% Fuel

3. Output

Among the most significant output generated by the glide-bang profile is the inclination change and the heating rate. These charts will be used as a standard for comparing the other maneuvers in which the heating rate is controlled. Figure 17 shows the inclination change for the various fuel percentages. Not included in the maneuver is

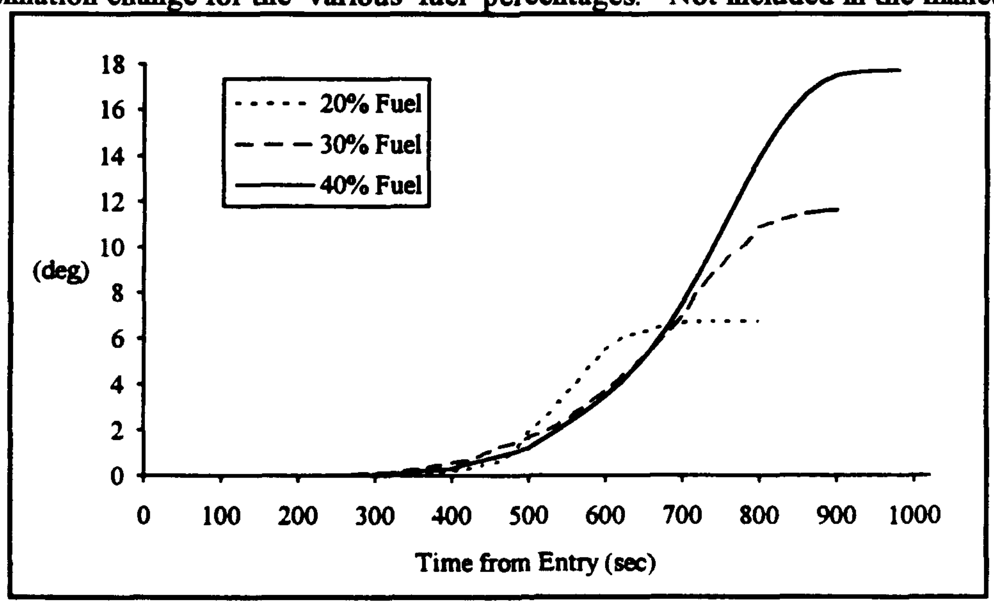

Figure 17. Inclination Change

the amount of inclination change that could be obtained during the deorbit and reorbit (circularization) burns. These short burns could add as much as one degree to the maximum plane change obtained by the entire maneuver. Hence, the figure shown indicates the maximum plane change obtained only during the atmospheric portion of the maneuver.

The instantaneous heating rate and the accumulated integrated heating load on the vehicle are shown in Figure 18. It can be seen that the peak heating rate during the unconstrained bang out of the atmosphere is approximately $2.0*10^6$ W/m^2 for 20% Fuel and about twice that ($4.0*10^6$ W/m^2) for twice the amount of fuel (40%). This is due to the vehicle flying in the atmosphere for a longer period of time when there is more fuel available.

Another examination of the heating rate figures is required to determine where the higher and lower boundaries should be for the heating control maneuvers. One boundary should be chosen which is easily maintained and one should be chosen that will be a challenge to maintain. The selection of $1.41*10^6$ W/m^2 ($\approx$125 BTU/ft^2 sec) and $9.6*10^5$ W/m^2 ($\approx$85 BTU/ft^2 sec) is consistent with this premise and with previous researchers [Ref. 26].

The altitude and velocity profiles during the maneuver are shown next in Figure 19. The altitude profile is not unexpected, as increasing amounts of fuel allow the vehicle to stay in the atmosphere longer. A longer time in the atmosphere means more aeroassisted inclination change has been generated. The velocity profile shown is computed as the Kepler Number, which is defined as the vehicle's local atmospheric velocity divided by the circular velocity (note that this is for a rotating earth and atmosphere). A Kepler Number less than 1.0 would be a sub-circular speed. As the vehicle enters the atmosphere, it's speed is maintained as it glides down. The vehicle begins it's "pull out" with engines firing and the lift vector rolling to local vertical. This lift vector rotation is accomplished by the decreasing bank angle and increasing angle of attack. This move also slows the vehicle down initially, then the continual thrust from the

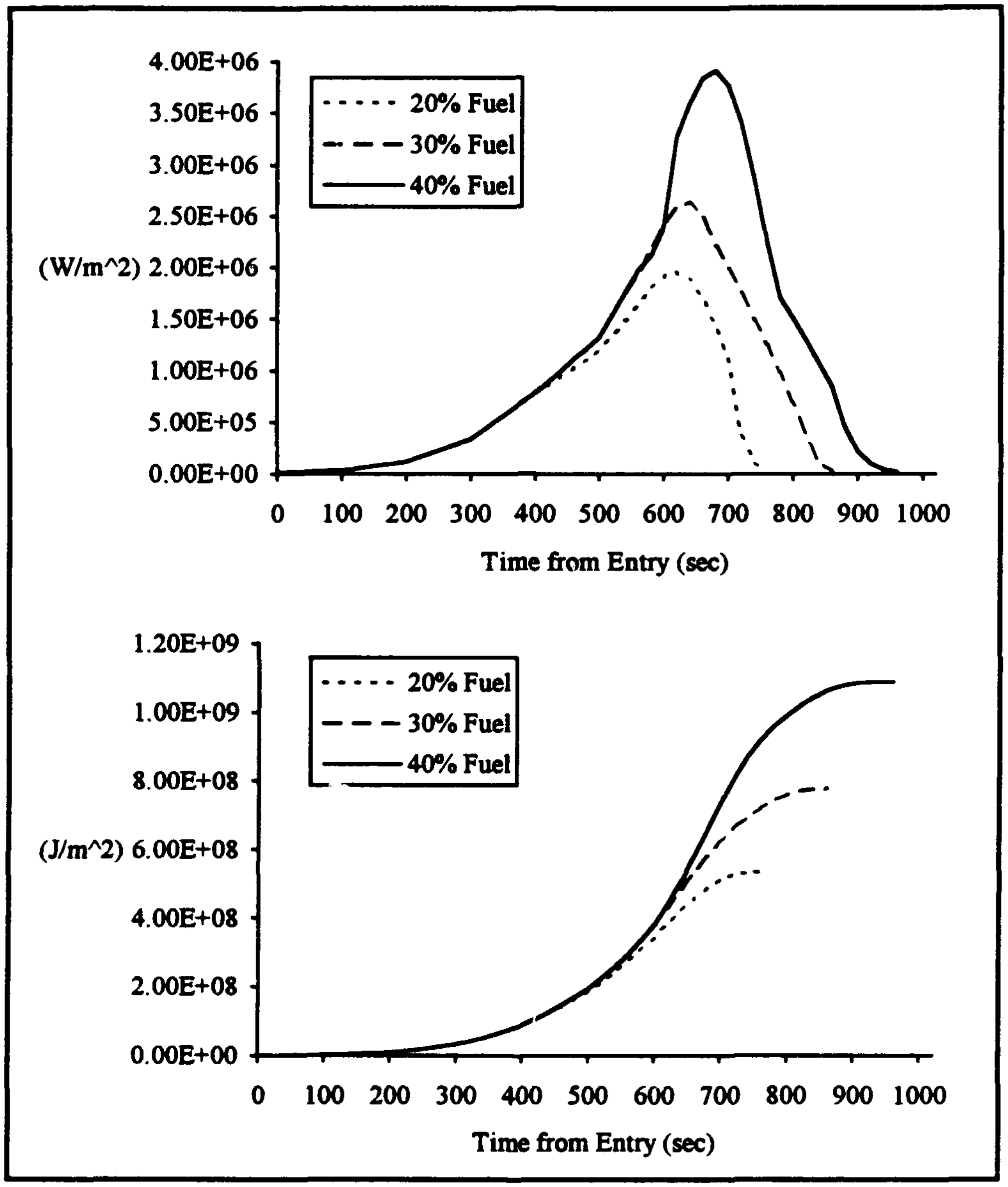

Figure 18. Instantaneous Heating Rate (top) and Integrated Heat Load (bottom)

engines begins to have an effect and the vehicle speeds up to reboost to orbit altitude. After the engines are shut off, the vehicle begins to slow, since it is still encountering drag in the atmosphere and the force of gravity. Although not shown, after exiting the atmosphere, the vehicle would pick up some speed (no drag) but would need a brief circularization burn when obtaining orbit altitude.

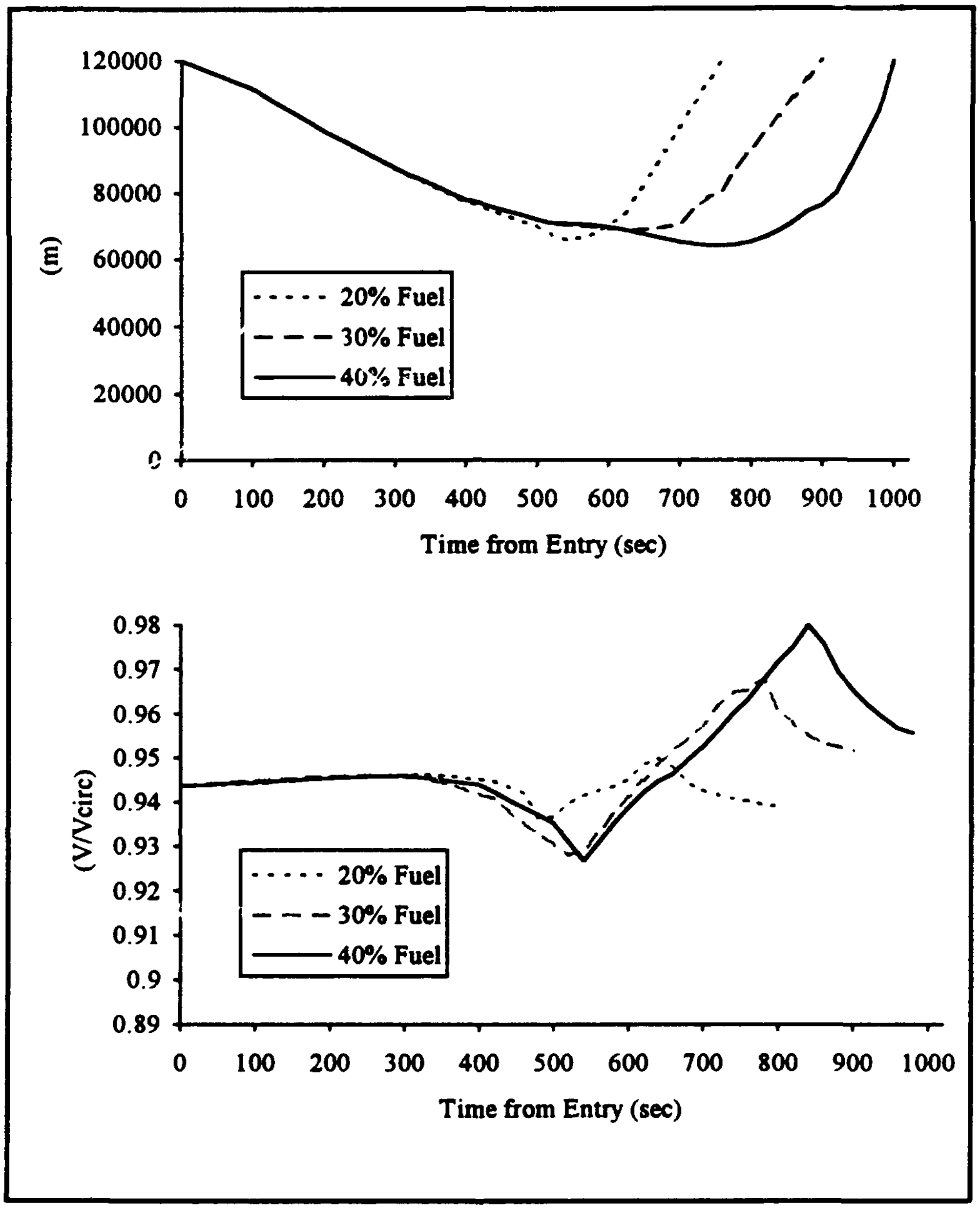

Figure 19. Altitude and Velocity Profiles

Another factor that should be considered is the acceleration loading on the vehicle. This factor, although quite important in reality, is difficult to implement in equation form and not usually included in calculations of these proposed maneuvers. If a sustained "20-g's" is required to perform these turns, , the maneuver will not be practical from a manned mission point of view. POST includes options to calculate the loading

during the maneuver, based on variables that are input to the program's vehicle module. For the Entry Research Vehicle and this maneuver, the acceleration loading is quite small. Figure 20 depicts the sustained loading on the vehicle, and it is insignificant. This is due partly to the control profile selected above, where the rates of change of the angle of attack and bank were used as controls in the trajectory events. Since POST calculates this model as a point mass with vehicle characteristics, the g-loading at only the center of mass is considered.

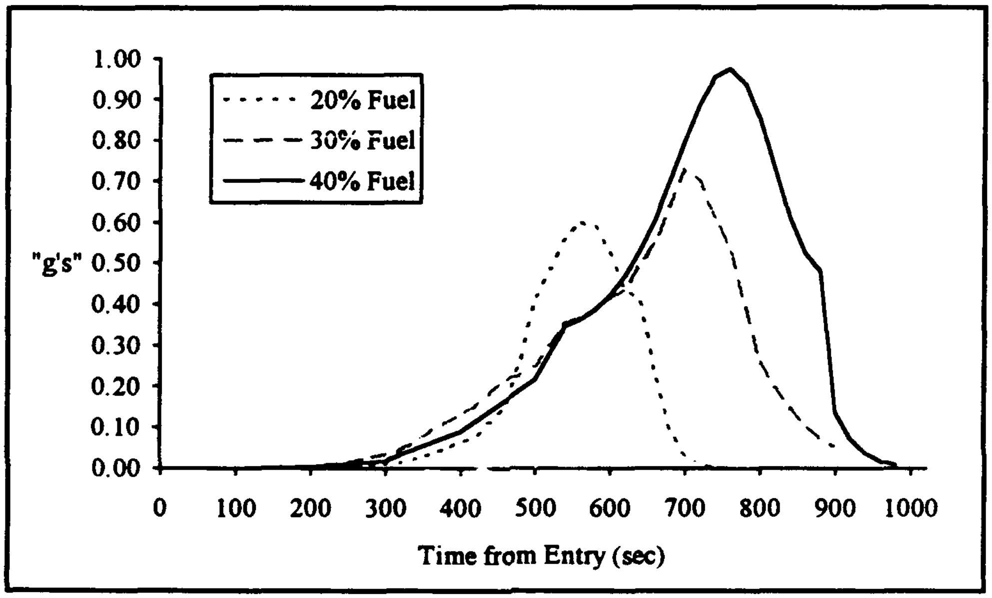

Figure 20. Acceleration Loading during Maneuver

C. GLIDE - CRUISE - BANG

1. Input

The aerocruise maneuver, described as a "glide-cruise-bang" trajectory, was perhaps the most difficult profile to translate into POST. After a working aeroglide profile for a particular fuel weight was completed and the break times in the control history selected, the aerocruise input deck was run. Invariably the nominal trajectory would fail, even though it was the workable solution for aeroglide. This was due in large part to the flight path angle, γ. Aerocruise's heating controls assumed a circular path and

a steady-state cruise. In this simulation, the cruise maneuver was started at a point in time along the glide trajectory, and cruise's controls (throttling and bank angle) do not have the authority to bring the trajectory back into the feasible region. Part of this can be identified in the cruise bank angle equation from Chapter II, where an arccosine function is required. When cruise is given the input from the aeroglide optimal trajectory, this function is greater than unity for several seconds. This problem was fixed to a certain extent by having POST target the rate of change of the flight path angle (Chapter IV). It also required repeated modifications of the nominal trajectory until a working solution was obtained.

Optimal solutions were also difficult to attain. It has been suggested that the steady-state aerocruise is nonoptimal in many cases [Refs. 11,15]. POST, however, should still converge to an answer that is the best that it could do with this input trajectory, i.e., an "optimal solution." Final results were achieved that were consistent and optimal as far as POST was concerned. The average number of runs required to get a optimal solution was 20, with an additional 10 to get consistent optimal results (a pseudo-global optimum).

2. Controls

For the glide portion of aerocruise, the aerodynamic angles of attack and bank were the free variables for POST. The angle of bank during the heat rate control portion was derived from the input tables (Chapter IV) and the rate of change of the angle of attack was free for POST to use for targeting and optimizing. The rate of change of both angles was also free during the bang phase and the following coast phase. Figure 21 illustrates both these control histories for aerocruise with 30% fuel.

The thrust profile is also indicated in Figure 21. The use of thrust to maintain a circular path vice using it to perform part of the plane change does have an effect an the amount of inclination achieved. However, it also performs it's role in the heat rate control scheme. These effects will be discussed further in the next section.

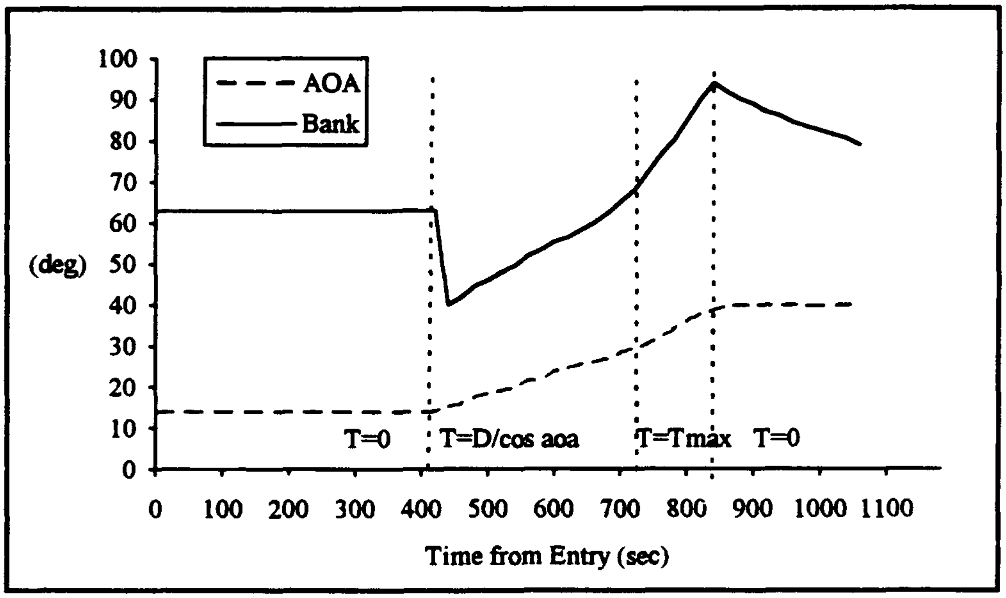

Figure 21. Control History for 30% Fuel

Note that the angle of bank during the glide phase is much less than for the same phase in aeroglide. This is due to the program using the portion of the lift vector in the local vertical plane to effect a "pull-up" on the vehicle. This causes the flight path angle to approach zero by the beginning of the cruise heat control event (see Figure 22). This enables the steady-state cruise control scheme to be effective.

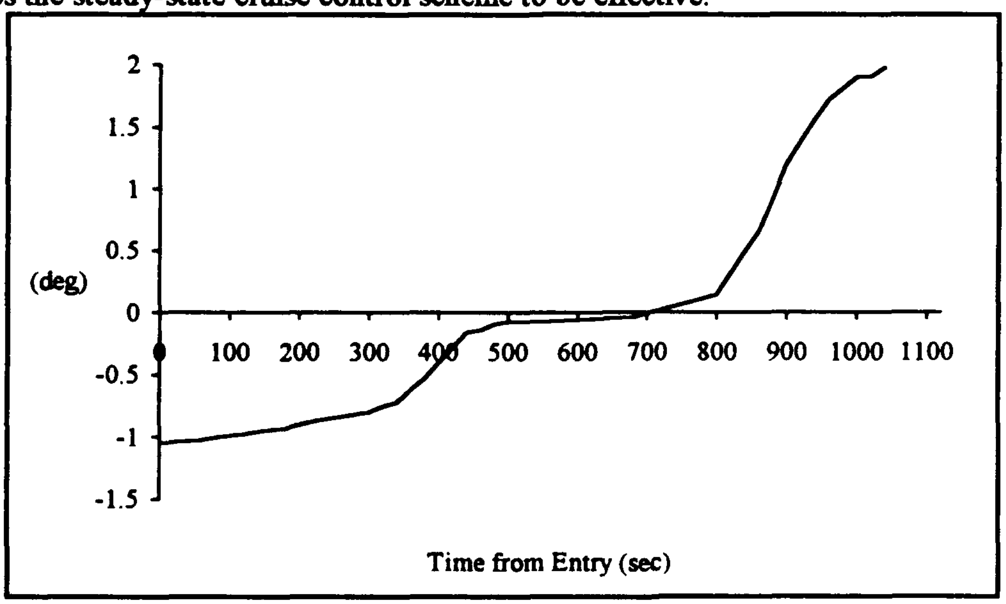

Figure 22. Flight Path Angle for 30% Fuel

3. Output

Figure 23 depicts the inclination change of the aerocruise maneuver for the different fuel percentages and the two heating rates. It can be seen that there is a definite loss of inclination change with a lower heating rate, since the thrust must be used in the control scheme to counter the drag forces. Again, the amount of inclination change (approximately one degree) that could be obtained during the deorbit and reorbit (circularization) burns is not included.

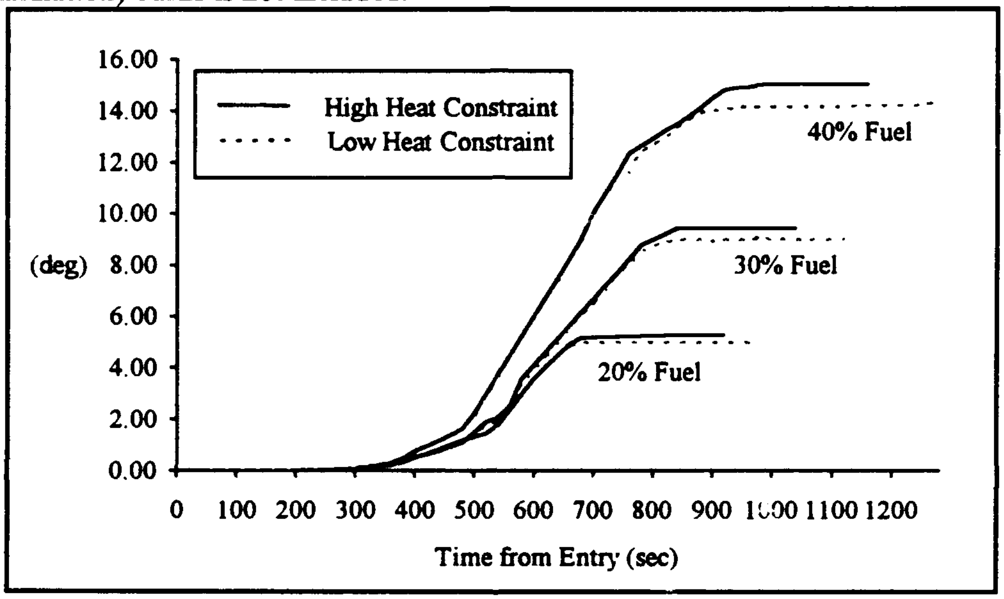

Figure 23. Inclination Change

The instantaneous heating rate on the vehicle is shown in Figure 24. The high and low constraint levels are depicted along with the unconstrained heating rate. The effectiveness of the cruise maneuver in controlling this heat rate can be evaluated from these charts. It can be seen that for the higher constraint, cruise manages the heating level quite well, with heat rates from 0% to 14% over the limit. However, the lower rate is more difficult to maintain, with rates going 15% to 75% over the limit.

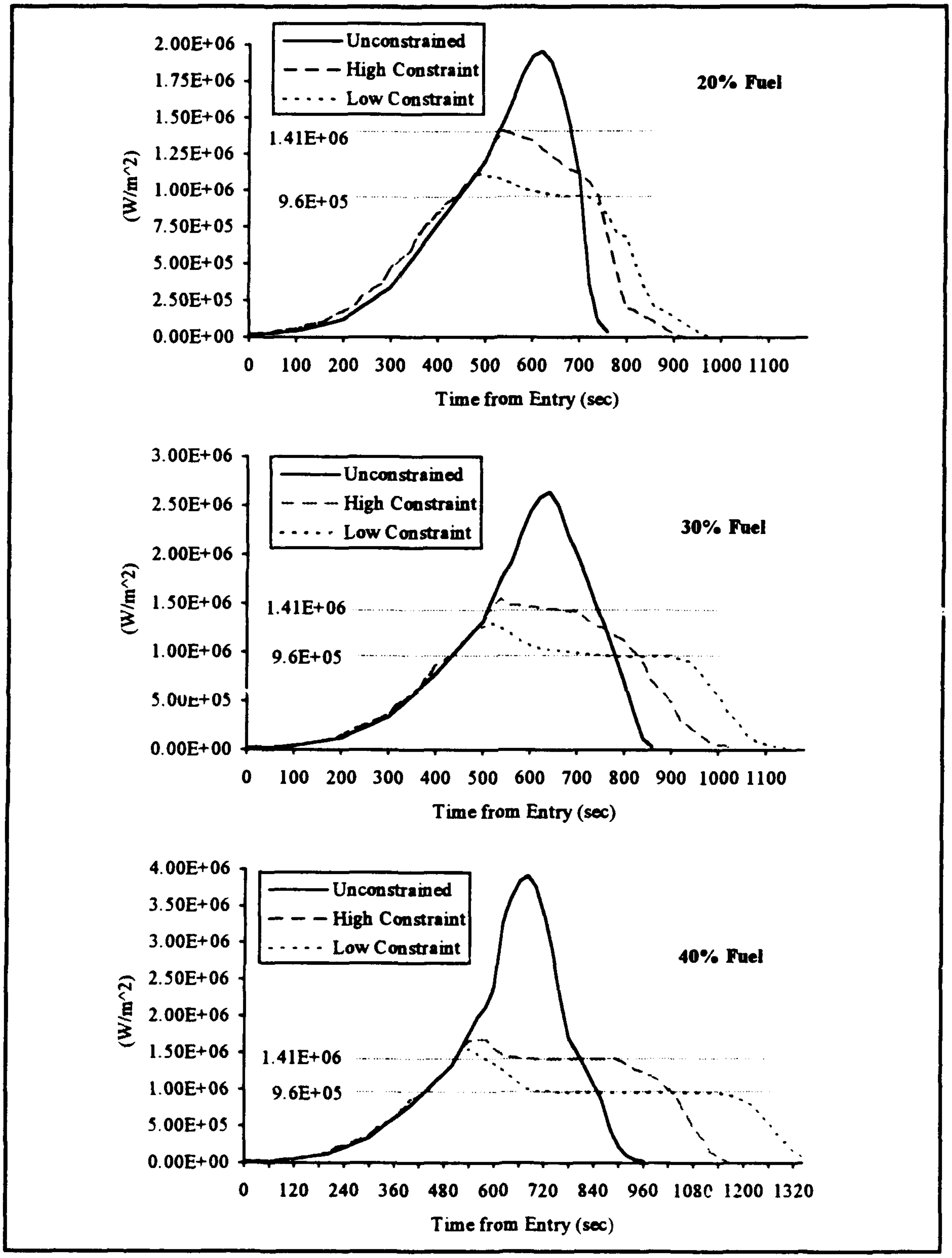

Figure 24. Instantaneous Heating Rate

The accumulated heat load is shown in Figure 25. This is just for a fuel percentage of 30%, but it is an excellent example. It can be seen that the total amount of heat encountered is about the same in the different maneuvers, it is how the maneuver distributes it over time that makes the difference.

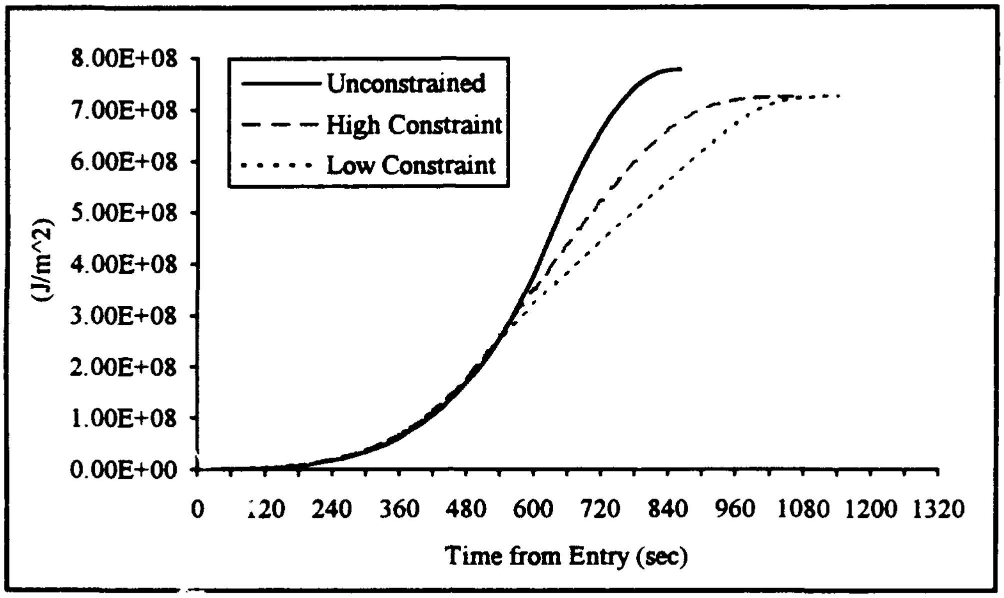

Figure 25. Integrated Heat Load for 30% Fuel

The altitude and velocity profiles are shown next in Figure 26. The aerocruise maneuver's "desire" to fly at a constant radius and speed can be seen in these charts. The control scheme envisioned by the steady-state cruise, combined with POST's targeting of the flight path angle change produces this constant curve. In fact, these charts were the first indication that the predicted cruise was not performing correctly, and the flight path angle targeting had to be inserted in POST's input file. For 20% fuel, it is observed that cruise only lasts a short time and does not fly long at a constant altitude and speed. For the higher fuel percentages, the maintained altitude and velocity profile can be easily seen. Although the actual velocities are not indicated, the speeds during the heat rate control phase range from approximately 6500 m/sec to 7000 m/sec. This is slightly less than the speeds for aeroglide. In general, it could then be said that aerocruise is "slow" compared to the Kepler Numbers for the glide-bang maneuver.

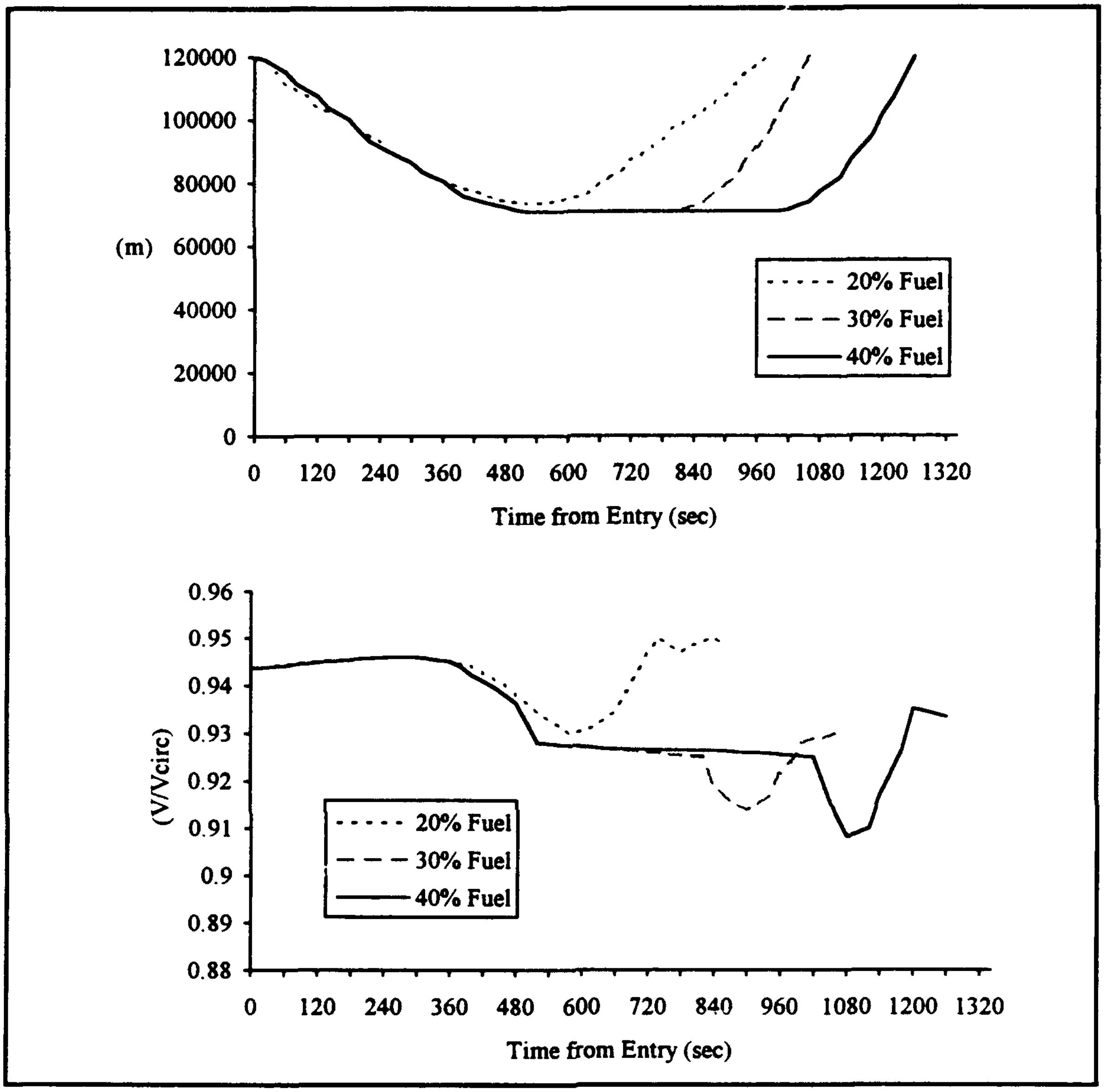

Figure 26. Altitude and Velocity Profile

Figure 27 indicates the loading on the vehicle. The significant peaks on this chart occur approximately at the end of the cruise phase of the maneuver, at the beginning of the full throttle bang phase that propels the vehicle back into orbit. Again, it should be noted that the acceleration loading on the vehicle is not very significant. Using the rates of change of the angles of attack and bank ensures that a reasonable flight profile will be used, but also contributes to the limited loading factor.

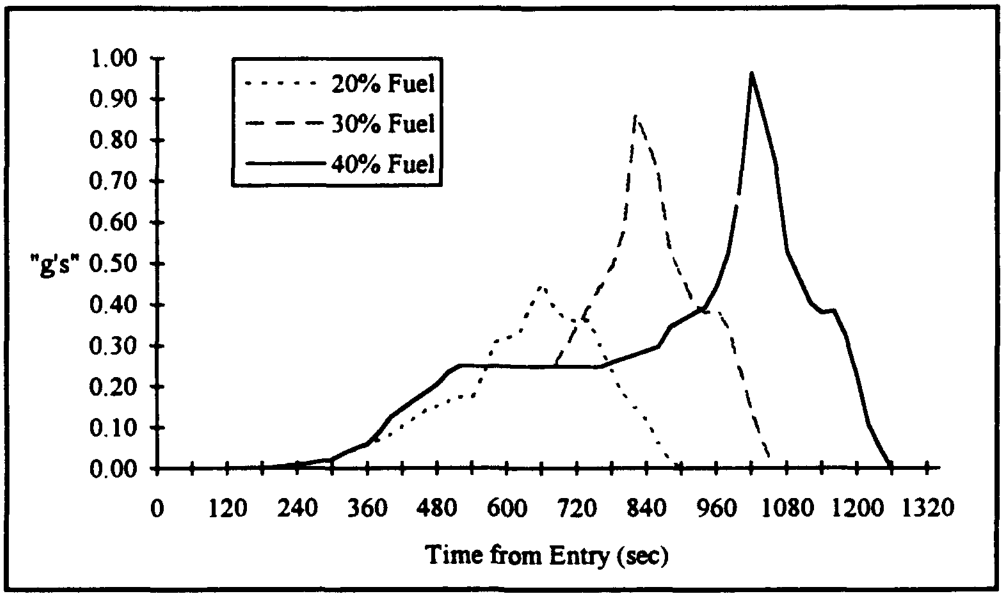

Figure 27. Acceleration Loading during Maneuver

D. GLIDE - CONSTRAINED BANG - BANG

1. Input

The aerobang maneuver, described as a glide-constrained bang-bang trajectory, was a remarkably robust control scheme. Despite the unorthodox method of deriving the correct angle of attack to control the heat rate, the maneuver consistently worked quite well. When provided the nominal trajectory from an optimized aeroglide, POST could usually converge to a near-optimal solution in one run. Refinements of the inputs around this trajectory provided what was deemed the "global optimum" solution to the problem. A total of five to eight runs were required for the aerobang to produce a consistent optimum.

This was due in part to the equations for the angle of attack controls. Referring to the equations from Chapter II, it can be seen that a heat rate factor (ξ) is included in the equations. Although this is from an idealized heating rate equation and an exponential atmosphere, it still provides a more robust control equation. The other factor that is accounted for in aerobang is the flight path angle, γ. Since this angle is included, there is a clear link between the equations of motion and the heat rate controls. Aerobang does not

depend on a steady-state condition to happen. This freed POST from having the additional targeting problem of the rate of flight path angle change, as aerocruise's runs were required to do.

2. Controls

For the glide portion of aerobang, the aerodynamic angles of attack and bank were controls for POST. During the heat rate control phase, the angle of attack was derived from the input tables as discussed in Chapter IV while the rate of change of the bank angle was free for POST. During the boost and coast phases, the rates of change of both aerodynamic angles were used as control variables for the program as well. The break times for the events were selected from the glide-bang trajectory.

The control history for 30% fuel, high heat constraint case is shown in Figure 28. This a typical profile for the aerobang maneuver. When POST completed optimizing the constrained bang runs, the initial angle of bank was less then that from the aeroglide (≈ 95°) but more than that from aerocruise (≈ 65°). The angle of attack was slightly more than $(L/D)_{max}$ during the glide, then increasing to the maximum of 40° while the bank

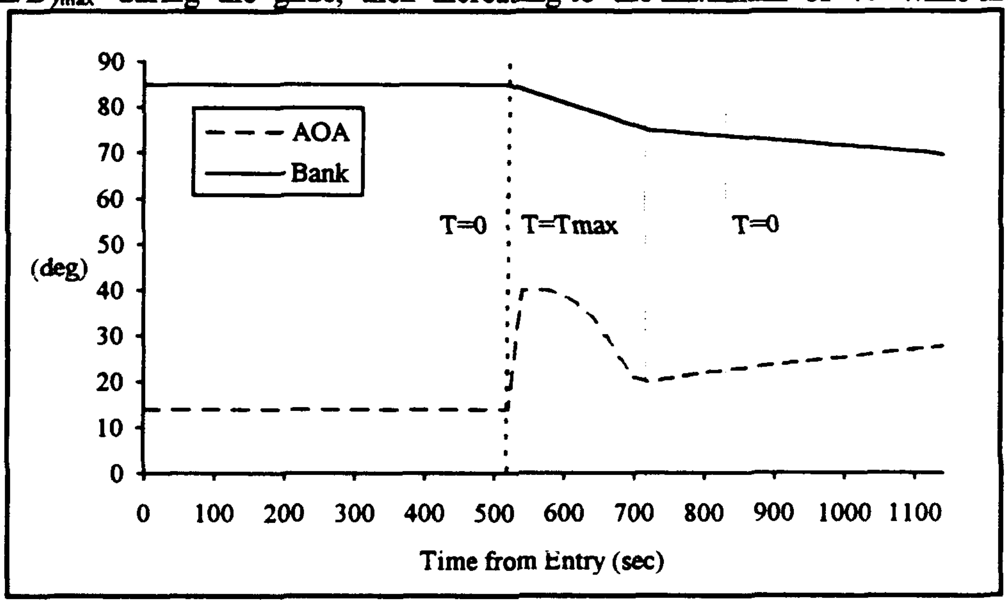

Figure 28. Control History for 30% Fuel

angle begins decreasing. As this causes the lift vector component in the local horizontal to increase and begin pull-out, the heat rate constraint can be maintained or brought back within limits. Thrust was at a maximum these phases, as indicated in the figure.

3. Output

The inclination change for constrained bang is shown in Figure 29. The different fuel percentages as well as the two heating levels are indicated on the charts. The inclination change is significant, but not as great as that achieved by the unconstrained glide-bang maneuver.

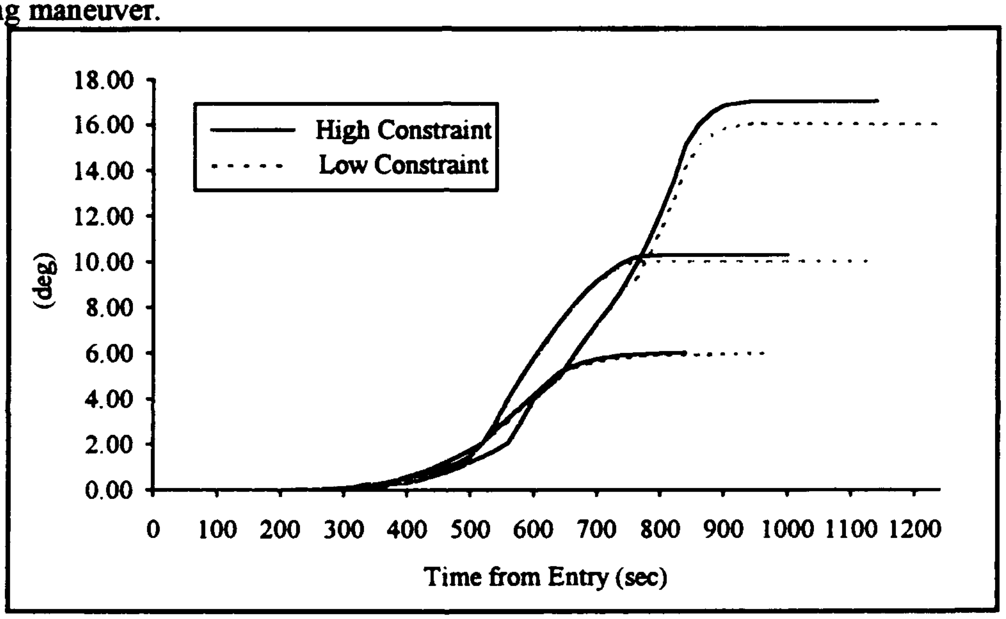

Figure 29. Inclination Change

The instantaneous heating rate is indicated in Figure 30. High and low constraints levels are depicted along with the unconstrained heating rate. The effectiveness of the aerobang is evaluated in terms of percentage overshoot, similar to the aerocruise maneuver evaluation. For the higher limit, constrained bang manages the heating level within 0% to 17% over the limit. For the lower level, the heating is maintained from 0% to 33% past the limit. One of the reasons constrained bang manages the heating rate quite well is due to the inclusion of a heating rate factor (ξ) in the control equations (Chapter II).

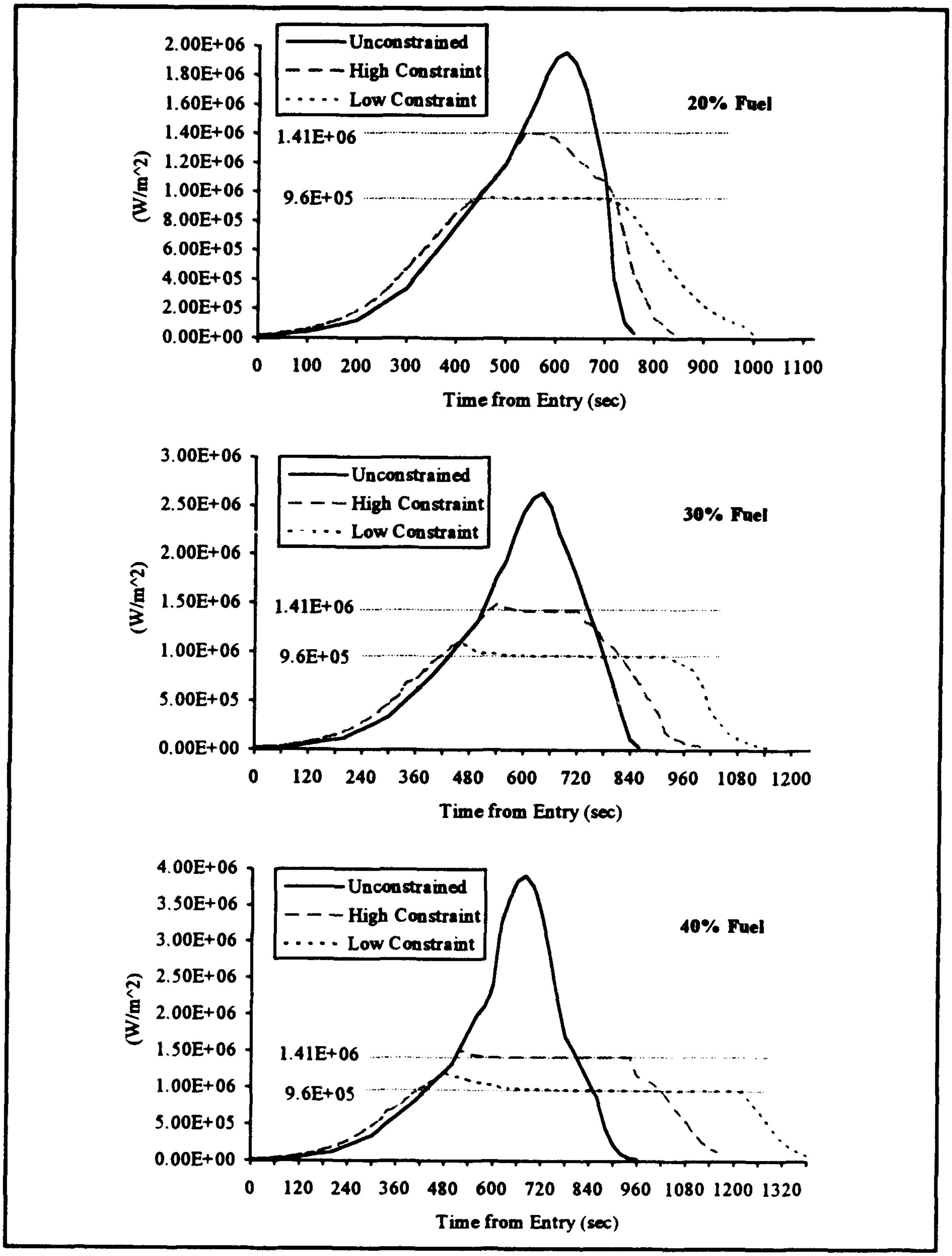

Figure 30. Instantaneous Heating Rate

The accumulated heat rate for a fuel percentage of 30% is shown in Figure 31. The total amount of heat encountered during the atmospheric pass is the same for each maneuver. The difference is in the how this heat is distributed over time.

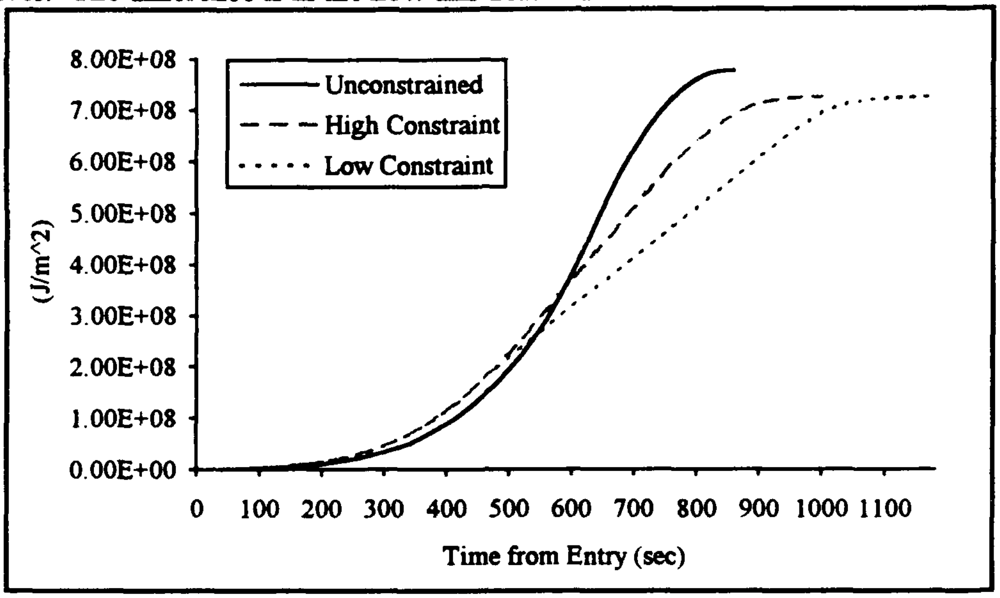

Figure 31. Integrated Heat Load for 30% Fuel

The altitude and velocity profiles during the maneuver are shown next in Figures 32 and 33. It should be noted that the aerobang is somewhat "faster" in terms of Kepler's Number. Although both maneuvers require the vehicle to slow, the full thrust

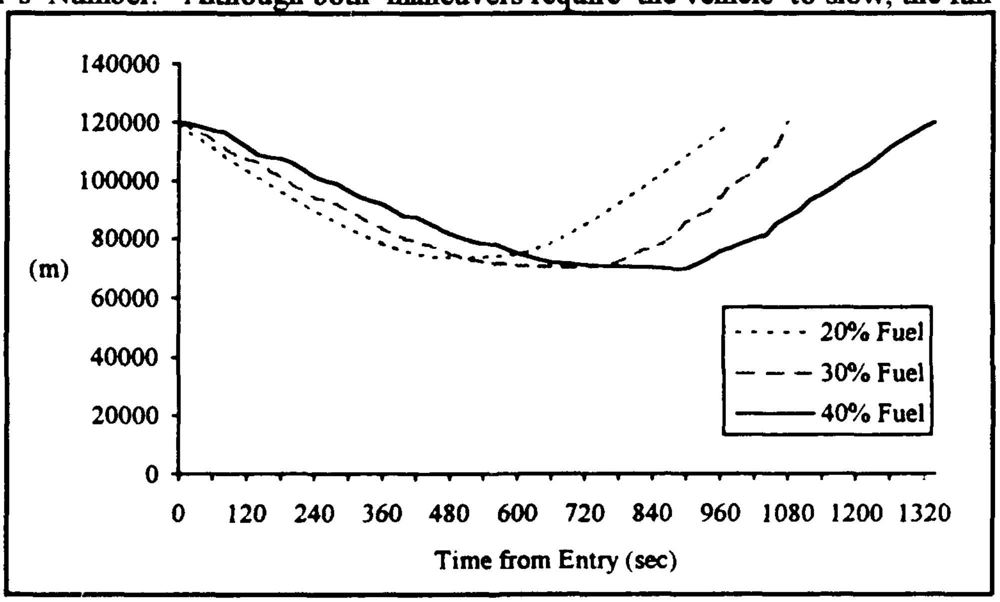

Figure 32. Altitude Profile

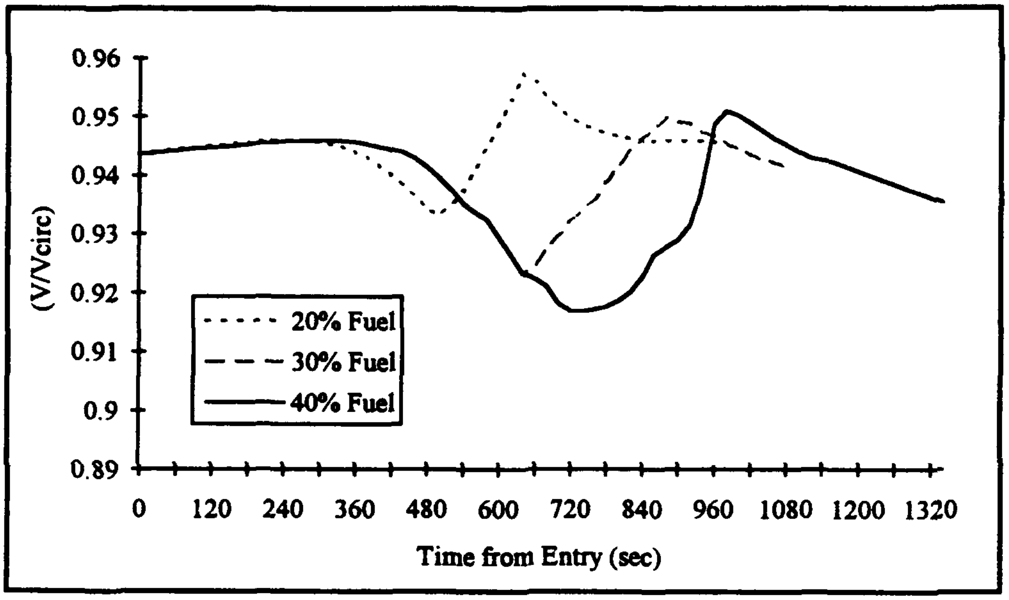

Figure 33. Velocity Profile

maneuver of constrained bang tends to make this decrease in speed a momentary dip in the velocity profile. Since the amount of lift generated is related to the velocity of the vehicle, going faster generates more lift which provides more force to aid in the aerodynamic turn. This translates to a larger inclination change.

G-loads during the maneuver for constrained bang is insignificant as it was the other maneuvers (see Figure 34).

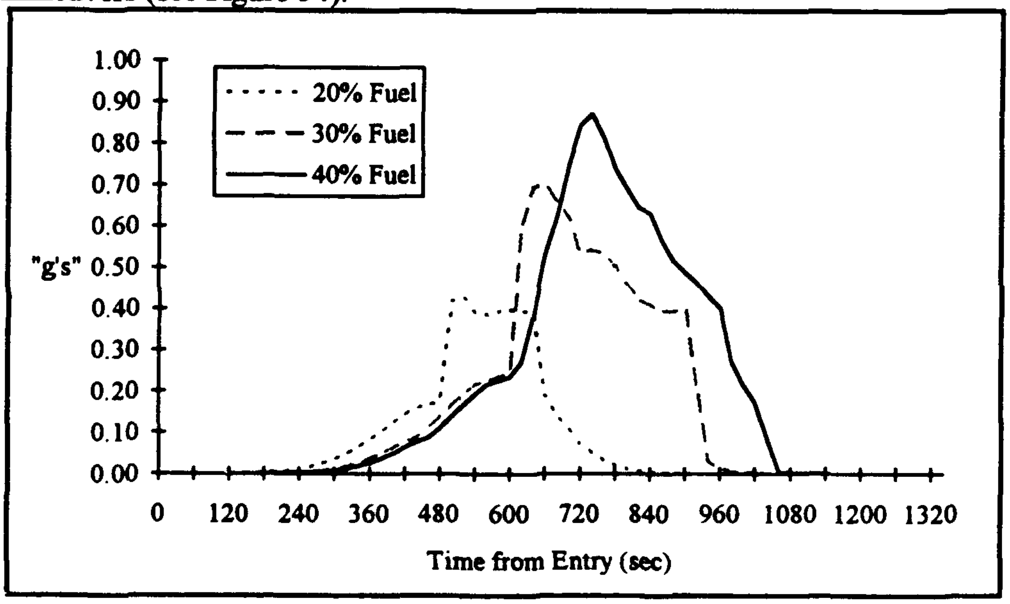

Figure 34. Acceleration Loading during Maneuver

E. COMPARISON OF MANEUVERS

1. Inclination Change

A comparison of the amount of inclination change that each maneuver produces is summed up best by Figure 35. This is the amount of inclination change achieved by an ERV model simulated to begin at a 300 km altitude circular orbit and return to a similar orbit. The ERV's weight is approximately 50,000 Newtons and the fuel percentages shown weigh 10,000 to 20,000 Newtons. Inclination change due to deorbit and recircularization burns is not included, but varies from approximately 0.5° (20% fuel) to 1.25° (40% fuel). The high and low heat rate levels are indicated in the figure and the slight decrease due to more restrictive heat constraints is noted. The glide-bang trajectory clearly produces the most inclination change, with the constrained bang maneuver the better of the two heat rate control schemes.

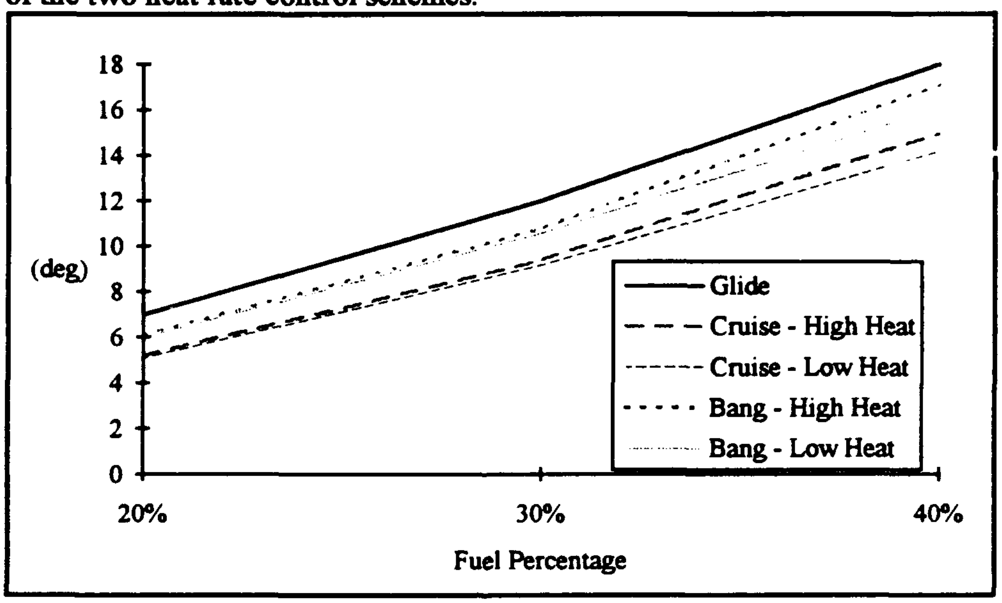

Figure 35. Inclination Change versus Fuel Percentage

A comparison should also be made between the aeroassisted maneuver and the pure propulsive case. Although regularly stated that it was superior, a brief numerical analysis is beneficial. Using the equation for the speed of a circular orbit

$$v_{circ} = \sqrt{\frac{\mu}{r}}$$

where μ is the gravitational parameter for the earth and r is the distance from the earth's center. For constant thrust,

$$\Delta v = I_{SP}\, g_o \ln (m_i / m_b)$$

where I_{SP} is specific impulse, g_o is the acceleration due to gravity at the surface, and m_i and m_b are the initial masses and burnout masses respectively. With the equations in place, the inclination change ($\Delta\, i$) for a pure propulsive maneuver can be found from

$$\Delta\, i = 2 \sin^{-1} (\Delta v / 2\, v_{circ})$$

This comparisons shown in Figure 36 are based on this equation.

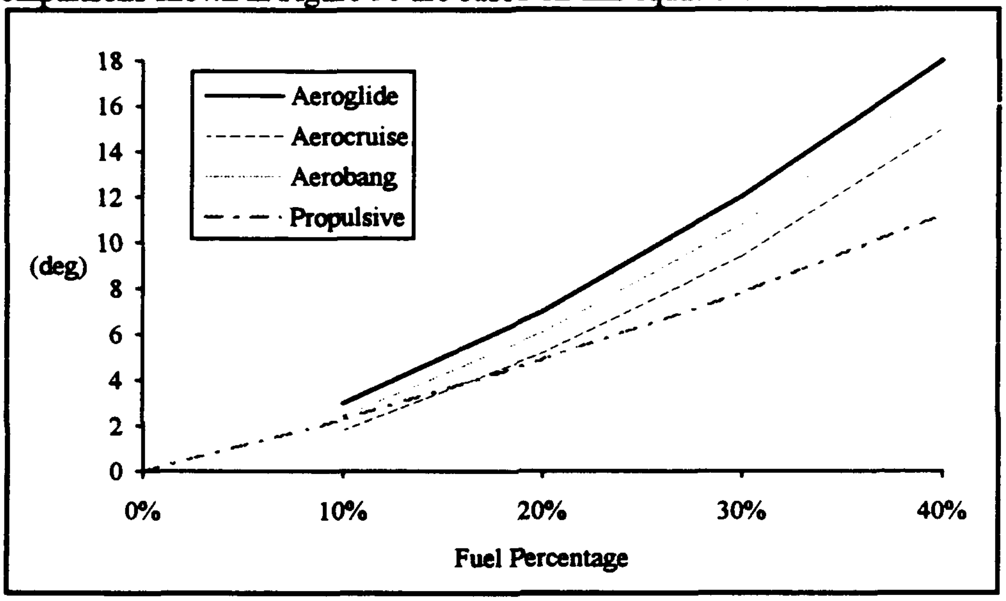

Figure 36. Propulsive versus Aeroassisted Inclination Change

Figure 36 has extrapolated the left end of the various aeroassisted maneuvers so that a comparison can be made with decreasing amounts of fuel. It can be seen in the figure that for inclination changes less than three degrees, the pure propulsive maneuver is probably more efficient. However the savings for large inclination changes is substantial and a motivating reason for studying the aeroassisted maneuver.

2. Heat Rate Control

Since the aeroassisted maneuver indicates that it would be useful for large plane changes, the concept of thermal protection must be considered. If the thermal protection

system on a vehicle must be very complex and robust, any savings achieved by an aeroassisted maneuver would be negated. This is the motivating reason for setting two different heating levels and examining how well the heat rate control schemes actually work.

Figure 37 shows the cruise and constrained bang control schemes for the two heating level and 30 percent fuel. The amount of overshoot may be reduced by implementing the control scheme earlier in the maneuver, but at the sacrifice of less inclination change. However, the thermal protection system probably has fixed limits and any violation of these limits would not be an "overshoot," but probable destruction of the vehicle.

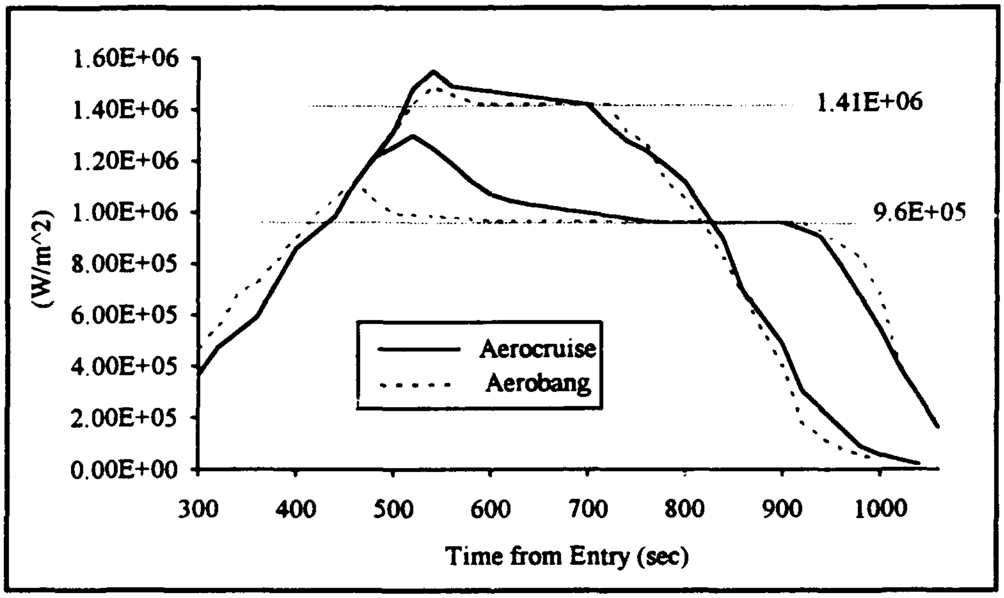

Figure 37. Heat Rate Control Comparison for 30% Fuel

3. "Best" Maneuver

To the question of "What is the best maneuver?" the answer must be "Depends." It is dependent on the vehicle characteristics in terms of thermal limitations, maneuverability, and propulsion capabilities. It is dependent on the amount of fuel available to perform an inclination change and the acceptable heating rate for a solution. Although all three proposed maneuvers work, there are definite advantages to the two

bang schemes. For a given amount of fuel, the glide-bang produces a large inclination change, but with a high heating rate encountered. The constrained bang produces nearly as large an inclination change, but with the heating rate effectively controlled. The aerocruise produces neither as much inclination change nor controls the heat rate as well. Therefore, for a desired inclination change and a heating rate tolerance limit, there is an optimal maneuver. The results of this thesis can be linearly interpolated and extrapolated to develop these "regions of optimality." They are depicted in Figure 38 for the Entry Research Vehicle.

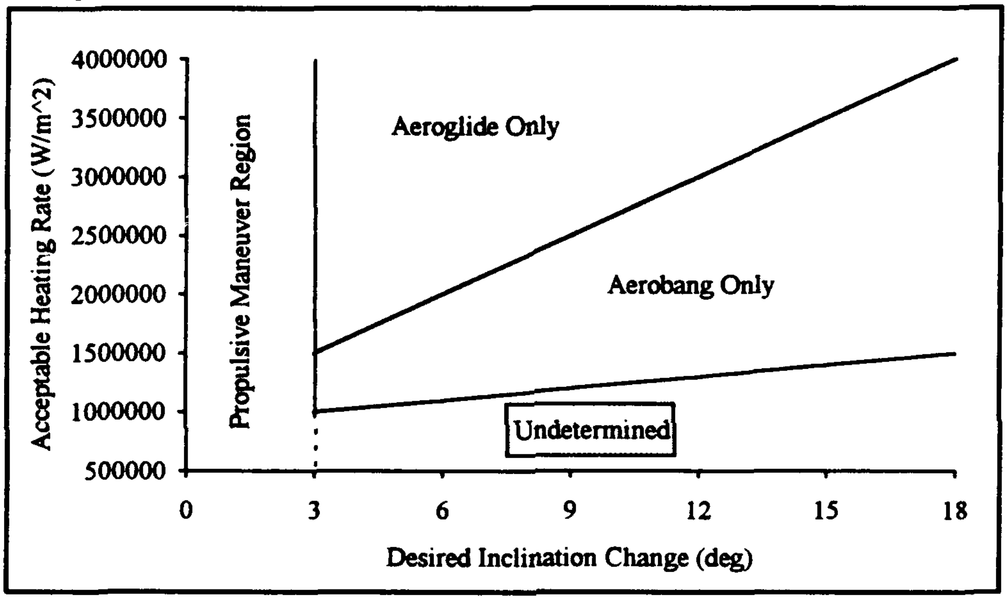

Figure 38. Optimal Maneuver for Desired Inclination Change and Given Heating Rate Limit

The lower limit of feasibility for the aerobang maneuver has not yet been determined. After deducing what the optimal maneuver should be from Figure 38, the amount of fuel could be determined from Figure 36 (for the ERV only). The aerobang appears to be the superior heat control scheme. If the heating rate is not an important consideration or the proposed vehicle has an adequate thermal protection system, the glide-bang maneuver will be the best maneuver for larger inclination changes. Finally, if the vehicle does not have an adequate thermal protection system, or the desired inclination change is small, the well understood pure propulsive maneuver is the best choice.

VI. CONCLUSIONS

A. SUMMARY OF RESULTS

The feasibility of the aeroassisted maneuver has been well documented in this thesis. By examining the entire trajectory, the true potential of the maneuver is revealed. The glide-bang profile holds the promise of nearly twice the inclination change as that for the propulsive maneuver, given no heat constraints. If the heat constraints are there, the constrained bang clearly demonstrates it's ability to maintain that heat rate while still providing a substantial inclination change. This thesis has also noted the difficulties in implementing the steady-state aerocruise. Although easy to analyze and model through equations, it proves difficult to use in a simulation where the entire flight trajectory is considered.

The timing of the plane change in the trajectory is also of interest. While the glide portion or the heat control portion perform their "job" in the trajectory, the majority of the plane change comes during the full throttle unconstrained bang back to orbit. This point is rarely emphasized in available literature, but it could be said that the introductory portions of the maneuver merely "set up" the vehicle for the plane change and boost back to orbit.

As with any simulation, there are certain weaknesses in this model. The most prominent one is the selection of break times in the control histories. Ideally, an optimization program would be able to decide when to change the controls and which controls to change. From the POST manual: "It is not generally a good idea to let the program pick both the break times and the controls for an event, although it may seem logical to do so." [Ref. 22:p. 8-5] Difficulties in having the program solve even simple trajectories were noticed when this subtle rule was violated. This problem entails a great deal of multi-dimensional optimization. There is no program available that can solve this in one step, and a good starting point is nearly always required to ensure targeting and optimization.

Another weakness in the simulation is the models used themselves. A point mass model with aerodynamic characteristics can certainly be used to solve many problems, but a detailed vehicle model is required to truly find what a vehicle would endure through an aeroassisted maneuver. The aeroheating model is also questioned. Chapman's equation provides an easy way to find the instantaneous heating rate, but it may not be valid for a vehicle that is maneuvering at Mach 20 at the extreme edge of it's operating envelope. Chapman's equation calculates the heating at the stagnation point, which is usually considered to be the vehicle nose. However, these vehicles are flying for sustained periods of time at high angles of attack and bank. At these high angles, the stagnation point may be elsewhere on the body and the vehicle may be undergoing more or less heating than has been reported. There is no way to know this but by flight test, and continuing analyses, models and simulations of this maneuver.

B. RECOMMENDATIONS FOR FURTHER STUDY

There are three main themes to be looked at in the future. One is to expand the scope of the current investigation, using other vehicle models and different maneuvers. Freeing up other aerodynamic variables for POST to use, allowing thrust to be controlled, or providing POST with all control variables and a set of constraints. Breaking up the maneuver in a different manner or using more events may also prove successful. More complex vehicle and heating models may provide more realistic results from the simulation. Along this line, there is a POST version that has six degrees of freedom, vice the three degrees of freedom version used here. This would provide more flexibility in setting up the problem. Changing the heat rate constraints will also yield new and different results, giving researchers more insight into this difficult problem.

The second point to be emphasized in the future should be on the optimization process itself. As mentioned, there are inherent limitations to every numerical optimization routine. Perhaps other techniques beside POST's accelerated projected gradient method will prove to be more robust and easier to implement. These other

nonlinear programming techniques may require the whole maneuver to be modeled differently, thus providing a different perspective on the problem.

Lastly, it is noted that the Entry Research Vehicle was designed to perform the aerocruise maneuver during a plane change, yet a constrained bang maneuver controlled heat better while providing more inclination change. What would a vehicle designed for aerobang look like? Or is there a better way of controlling heating while making the turn, such as a combination of angles and thrust? What would that vehicle look like? These are the questions that need to be answered in the future.

C. CLOSING REMARKS

The evolution of the synergetic plane change has been well documented. The synergetic plane change offers substantial fuel savings over the pure propulsive alternative for certain noncoplanar orbital transfers. On the other hand, the thermal environment for a synergetic plane change can be quite severe. The problem with developing an analytical model of these maneuvers is apparent with the multidimensional aspect of the constraints making any analysis extremely complex. The continuing increases in computing power have aided this study, since more accurate solutions can be obtained even though the problems incorporate more variances. Various optimization approaches are contributing new knowledge to the solution of the problem. Although the solutions are becoming more accurate, the limits of the experimental knowledge of the hypersonic flight envelope are quickly reached.

Aeroassisted orbital transfer offers a significant increase in payload delivery capability for a wide range of orbital transfers. While the theory of optimal all-propulsive transfer in space is quite complete, the theory of optimal aeroassisted orbital transfer is in the development stage. The goal of the this thesis is to continue the theoretical development to determine the best strategy, considering both all-propulsive and aeroassisted modes, for any given transfer, and to uncover the fundamental principles that characterize the best strategy. Aeroassisted orbital transfer introduces a strong coupling between the trajectory design and the vehicle design. A trajectory that minimizes fuel

mass, without attention to heating, may require the vehicle to have a heavy thermal protection system. If aeroassisted transfer is to be preferred to an all-propulsive maneuver, it must offer reduction in fuel mass greater than the increase in thermal protection mass. This thesis has examined one proposed vehicle in several different maneuvers and demonstrated the vast potential that the aeroassisted maneuver will have in the future.

LIST OF REFERENCES

1. Walberg, G. D., "A Survey of Aeroassisted Orbit Transfer," *Journal of Spacecraft and Rockets*, Vol. 22, No. 1, Jan.-Feb. 1985, pp. 3-18.

2. Cuadra, E. and Arthur, P. D., "Orbit Plane Change by External Burning Aerocruise," *Journal of Spacecraft and Rockets*, Vol. 3, March 1966, pp. 347-352.

3. Ross, I. M., "Aerobang: A New Synergetic Plane-Change Maneuver," presented at the AAS/AIAA Astrodynamics Conference, Durango, Colorado, August 1991, AAS Paper No. 91-418.

4. London, H. S., "Change of Satellite Orbit Plane by Aerodynamic Maneuvering," *Journal of Aerospace Sciences*, Vol. 29, March 1962, pp. 323-332.

5. Love, E. S. and Pritchard, E. B., "A Look at Manned Entry at Circular to Hyperbolic Velocities," Proceeding of the AIAA 2nd Manned Spacecraft Meeting, Dallas, Texas, April 1963, pp. 167-188.

6. Maslen, S. H., "Synergetic Turns with Variable Aerodynamics," *Journal of Spacecraft and Rockets*, Vol. 4, Nov. 1967, pp. 1475-1482.

7. Lau, Johann, "Implications of Maneuverings-Range Constraints on Lifting-Vehicle Design," *Journal of Spacecraft and Rockets*, Vol. 4, May 1967, pp. 698-700.

8. Wurster, K. E. and Eldred, C. H., "Technology and Operational Considerations for Low-Heat-Rate Entry Trajectories," *Journal of Spacecraft and Rockets*, Vol. 17, No. 5, Sept.-Oct. 1980, pp. 459-464.

9. Ikawa, H. and Rudiger, T. F., "Synergetic Maneuvering of Winged Spacecraft for Orbital Plane Change," *Journal of Spacecraft and Rockets*, Vol. 19, No. 6, Nov.-Dec. 1982, pp. 513-520.

10. Miele, A., Lee, W. Y. and Mease, K. D., "Nearly-Grazing Optimal Trajectories for Noncoplanar, Aeroassisted Orbital Transfer," *Journal of the Astronautical Sciences*, Vol. 36, Nos. 1/2, January-June 1988, pp. 139-157.

11. Ross, I. M., "The GLC and Optimality of the Aerocruise Maneuver," presented at the AAS/AIAA Astrodynamics Conference, Durango, Colorado, August 1991, AAS Paper No. 91-530.

12. Mease, K. D., "Optimization of Aeroassisted Orbital Transfer: Current Status," *Journal of the Astronautical Sciences*, Vol. 36, Nos. 1/2, January-June 1988, pp. 7-33.

13. Mease, K. D., Lee, J. Y., and Vinh, N. X., "Orbital Changes during Hypersonic Aerocruise," *Journal of the Astronautical Sciences*, Vol. 36, Nos. 1/2, January-June 1988, pp. 103-137.

14. Vinh, N. X., *Optimal Trajectories In Atmospheric Flight*, Elsevier Scientific Publishing Co., Amsterdam, 1981.

15. Spriesterbach, Thomas P., "Performance Analysis of Non-Coplanar Synergetic Maneuvers," M.S. Thesis, Naval Postgraduate School, 1991.

16. Anderson, J. D., *Hypersonic and High Temperature Gas Dynamics*, McGraw-Hill Series In Aeronautical and Astronautical Engineering, New York, 1989.

17. Bazaraa, M. S. and Shetty, C. M., *Nonlinear Programming, Theory and Algorithms*, Wiley and Sons, New York, 1979.

18. Bryson, A. E. and Ho, Y. C., *Applied Optimal Control: Optimization, Estimation and Control*, Wiley and Sons, 1975.

19. Shi, Y. Y., Nelson, R. L., and Young, D. H., "Optimal Aeroassisted Orbital Plane Change Using Collocation and Nonlinear Programming," presented at the NASA Flight Mechanics/Estimation Theory Symposium, Greenbelt, Maryland, May 1990.

20. Brauer, G. L., Cornick, D. E., Olson, D. W., Peterson, F. M., and Stevenson, R., "Program to Optimize Simulated Trajectories (POST)," Volume I, Formulation Manual, NAS1-18147, September 1990.

21. Brauer, G. L., Cornick, D. E., and Stevenson, R., "Capabilities and Applications of the Program to Optimize Simulated Trajectories (POST)," NASA CR-2770, February 1977.

22. Brauer, G. L., Cornick, D. E., Olson, D. W., Peterson, F. M., and Stevenson, R., "Program to Optimize Simulated Trajectories (POST)," Volume II, Utilization Manual, NASA-18147, September 1990.

23. Freeman, D. C., Powell, R. W., Naftel, J. C. and Wurster, K. E., "Definition of an Entry Research Vehicle," *Journal of Spacecraft and Rockets*, Vol. 24, No. 3, May-June 1987, pp. 277-281.

24. Powell, R. W., Naftel, J. C. and Cunningham, M. J., "Performance Evaluation of an Entry Research Vehicle," *Journal of Spacecraft and Rockets*, Vol. 24, No. 6, Nov.-Dec. 1987, pp. 489-495.

25. National Oceanic and Atmospheric Administration, National Aeronautics and Space Administration, and the United States Air Force, *1976 U. S. Standard Atmosphere*, October, 1976.

26. Mease, K. D. and Utashima, M., "Effect of Heat Rate Constraint on Minimum-Fuel Synergetic Plane Change," presented at the AAS/AIAA Spaceflight Mechanics Meeting, Houston, Texas, February 1991, AAS Paper No. 91-162.

BIBLIOGRAPHY

1. Menees, G. P., Brown, K. G., Wilson, J. F. and Davies, C. B., "Aerodynamic Heating and Performance Analysis of a High-Lift Aeromaneuvering AOTV Concept," *Journal of Spacecraft and Rockets*, Vol. 24, No. 3, May-June 1987.

2. Calise, A. J., "Singular Perturbation Analysis of the Atmospheric Orbital Plane Change Problem," *Journal of the Astronautical Sciences*, Vol. 36, Nos. 1/2, January-June 1988,.

3. Cervisi, R. T., "Analytical Solution for a Cruising Plane Change Maneuver," *Journal of the Spacecraft and Rockets*, Vol. 22, No. 2, March-April 1985.

4. Menees, G. P., Tauber, M. E., Wilson, J. F., Yang, L. and Adelman, H. G., "Entry Aeromaneuvering Capabilities of Transatmospheric Vehicles," presented at the AIAA Aerospace Sciences Meeting, Reno, Nevada, January 1988, AIAA Paper No. 88-0300.

5. Hsu, F., Kuo, T. and Chern, J., "Optimal Aeroassisted Orbital Plane Change with Heating-Rate Constraint," presented at the AIAA Aerospace Sciences Meeting, Reno, Nevada, January 1988, AIAA Paper No. 88-0301.

6. Jezewski, D. J., "Autonomous Optimal Deorbit Targeting," presented at the AAS/AIAA Spaceflight Mechanics Meeting, Houston, Texas, February 1991, AAS Paper No. 91-136.

7. Spriesterbach, T. P. and Ross, I. M., "Effect of Heating Rate on the Fuel Efficiency of Aerocruise and Aerobang Maneuvers," Department of the Navy, Naval postgraduate School, Monterey, California, 1992.

8. Nelson, H. F., Editor, *Thermal Design of Aeroassisted Orbital Transfer Vehicles*, Volume 96 of the Progress in Astronautics and Aeronautics, AIAA, New York, 1984.

9. Bale, R. R., Mueller, D. D., and White, J. E., *Fundamentals of Astrodynamics*, Dover Publishing, New York, 1971.

10. Hill, P. and Peterson, C., *Mechanics and Thermodynamics of Propulsion*, Second Edition, Addison-Wesley, Menlo Park, 1992.

11. McCandless, R. S. and Cruz, C. I., "Hypersonic Characteristics of an Advance Aerospace Plane," presented at the AIAA Aerospace Sciences Meeting, Reno, Nevada, January, 1985, AIAA Paper No. 85-0346.

12. Larson, W. J. and Wertz, J. R., Editors, *Space Mission Analysis and Design*, 2nd Edition, Microcosm, Inc., Torrance, 1992.

APPENDIX A

A PRIMER FOR POST

I. OVERVIEW OF POST

The original 3D version of the Program to Optimize Simulated Trajectories (POST) was developed in 1970 as a Space Shuttle Trajectory Optimization Program. Since that time, the program has been significantly improved with additional capabilities in the area of vehicle modeling, trajectory simulation, and targeting and optimization. The program is capable of simulating and optimizing trajectories for a wide variety of aerospace vehicles operating in the vicinity of a single planetary body.

Martin Marietta Corporation modified the program under contract with NASA Langley. Several enhancements were made to develop the latest (1989) version of 3D POST, identified as Version 3.000.

POST is a generalized point mass, discrete parameter targeting and optimization program. POST provides the capability to target and optimize point mass trajectories for a powered or unpowered vehicle near an arbitrary rotating, oblate planet. The program is quite generalized, with features for various planet and vehicle models. The flexible simulation capability is augmented by an efficient discrete parameter optimization capability that includes equality and inequality constraints.

POST is written in Fortran 77 for use on Silicon Graphics and Sun computers.

II. RUNNING POST AT NPS

POST is already installed on the UNIX operating system in the Aerospace Department. After obtaining an account form the administrative personnel (Ha-134), one

should run through the basics of the Unix operating system and be familiar with the SGI workstations in the department's computer laboratory (Ha-138).

The Unix command language is not simple but it is similar to DOS. The minimal commands necessary to run POST are shown below. For more details, refer to the NPS Computer Center's **Unix Made Easy** handout. This fully explains the various commands required to move around the Unix operating system as well as the basics of transferring files between different systems. Remember that the handout was developed for the Computer Center's Unix system that is run on the Sun machines in In-141. There will be slight differences in the commands on the aero lab's machines.

Command	Definition	Example
cd (directory name)	change directory	> cd WorkSpace
ls	list files	> ls
ls -l	list long view of files	> ls -l
zip (filename)	available text editor	> zip sample1.inp
telnet (machine.dept)	remote login command	> telnet wasp.aa
lp (filename)	prints file	> lp sample1.inp

POST was sent to NPS in a compressed format that contained two different versions; one for the Silicon Graphics workstations and one for the Suns. The version installed on the system is the Sun workstation version. Since most of the machines in the computer lab are SGIs, one has to transfer to a Sun in order to obtain the proper output.

Command	Meaning
> telnet wasp.aa	Transfer to a Sun workstation, where initial log-on procedures begin again. Another available machine is hornet.aa.
> cd (directory name)	Change to the directory where POST input file resides.

> post <(filename.in) >(filename.out)	Invokes POST program with input file named *filename.in*. If the output filename is not entered (*filename.out*), the output will go directly to the screen. If the input filename is not specified, POST will enter the interactive mode and expect all input to be entered directly into the program (should be avoided).
> logout	Returns user to original machine.

POST generates several output files. These should be examined in the word processors available on the workstations (**Jot** and **Zip**) to ensure that they are in the correct format and to check on the approximate size. Any file over 20 pages (numbered by POST) should probably not be printed out in the lab. To print out the smaller files, type **lp** *filename*. This will route the file to one of the laser printers in the aero computer lab.

POST can generate extremely large files. Since the aero computer lab laser printers should not be used for output greater than 15-20 pages, the best alternative is the IBM 3800-3 Laser Printer (In-140) available through the NPS mainframe. An account can be obtained from center's admin personnel (In-147) and a tutorial session on the mainframe system should be attended to learn the basics of file management and movement. The following demonstrates how to get the files via FTP and print them out. This assumes basic knowledge of the mainframe's VM/CMS system and begins after the initial login.

Prompt: Command	Meaning
Ready; DDNLINK	Opens Internet connection.
Ready; FTP 131.120.149.13	Internet address for wasp.aa. This begins the file transfer protocol to exchange files. Wasp will prompt for logon.
Command: cd (directory name)	Change to directory where file resides.

Command: dir	List of files in current directory.
Command: get (filename) (newfilename.type)	Gets the file *filename* from wasp and stores it in the mainframe as filename *newfilename* and filetype *type*. If the mainframe filename is not of this form, the file will not transfer.
Command: quit	Return to the mainframe account.
Ready; FONT ST12	Sets font of output file (default size is quite small).
Ready; FILELIST	Enter file listing environment.
=> PRINT NEWFILENAME TYPE (CC	Type this at command prompt at bottom of screen. This will send the file to the IBM 3800 printer in In-140. Note space between filename and type. '(CC' ensures full width of output page is used.
=> QUIT	Exits the file listing environment.
Ready; LOG	Log off mainframe.

If there are further questions about FTP, telnet, or general mainframe procedures; the consultants in In-146 are the best source of information.

III. GENERAL DESCRIPTION OF POST

This section provides the basic procedures required in using the program. An execution of the program consists of (1) processing the input data for all phases of the current problem, (2) checking for input errors, (3) initializing the equations of motion, (4) propagating the trajectory until interrupted by the occurrence of the user-specified condition for the next event, (5) reinitializing the equations of motion with new user inputs for the event causing the interruption, (6) repeating steps 4 and 5 until the user-specified final event is reached, and (7) terminating the problem.

The user must first define the problem as a sequence of events. There must be at least two events for each problem, but there is no upper limit to the number of events. The user must specify the condition at which each event is to occur (i.e., variable name and value). If the problem requires targeting or optimization, the user must also include independent (control) variables, dependent (target) variables, and the optimization variable and specify at which events these variables and their values will take place. It should also be noted whether a given target is an equality, lower-bound, or upper-bound constraint. Each target variable should be affected by at least one control variable and there must be more controls than targets for any optimization to occur. Next, the user should identify the vehicle characteristics and specific program options required at each event. Any required tabular data such as aerodynamic coefficients, etc. should be included.

Translating the problem into an input file is the next step. POST requires one input file of *namelists* in the proper sequence. A namelist is a Fortran phrase for a specific type of input. The namelist format allows columns 2 through 80 to be used for input of variable names and values; all separated by commas. There are four namelists required in the input file. The first, $SEARCH, is required at the beginning of each problem followed by the namelist $GENDAT for each event in the problem. If a phase requires table input, namelist $TBLMLT must follow the $GENDAT for that phase. The $TBLMLT namelist is followed in turn by namelist $TAB for each table to be input in that phase. This basic namelist sequence must be followed and completes the input file setup. The procedure is to translate the data described in the problem into the appropriate program input variables. The details of the input file are covered in the next section.

There are several different output files generated by POST. The output file named in the execution of the program will contain the original input file as well as all the values of the variables at each event in the problem. Specific results from the calculations can also be contained in the output file if they are required at certain points in the problem. Other output files are the *profil* and *profila* files. These two files are data files containing the 90 main variables computed in the problem. *Profil* is in binary format and *profila* is in ASCII

format. These files are made especially for data manipulation and display. Additional variables can be added to the list of 90. The file named *summary* will also be output and contains the optimization results (variable name and value) for each phase of the problem. These files are covered in more detail later.

IV. INPUT FILE

The input file for a POST run has to be constructed in a certain way. The format and sequence are as important as selecting the variables for optimization. This section highlights some of the main points to keep in mind when building the input file.

A. Format

The format of the namelists in the input file are as important as the namelists themselves. It is a standard ASCII-type character format with each data line being 80 characters long. Column one (1) is reserved for print control characters, a "1" in the first column preceding the namelist symbol "$" ensures each line of input is include in the output file with any input errors made indicated by a "^". Columns 2-80 are reserved for data statements, each statement separated by commas. Simple variables can be as follows:

NAME1 = VALUE1, NAME2 = VALUE2, etc.

Subscripted variables may be input as an array or as individual elements. The first element of the array is assumed if no subscript is present on a subscripted input variable. The following example shows various methods of input that are all equivalent:

EVENT = 1.0, 1.0,

or

EVENT(1) = 1.0, EVENT(2) = 1.0,

or

EVENT = 1.0, EVENT(2) = 1.0,

B. Sequence

In the input file the first namelist, $SEARCH, is read once per problem. It contains all targeting and optimization variables as well as any conversion constants required in the problem. Namelist $GENDAT is read once per phase and contains all constant input data for that phase. The first phase $GENDAT should include all program controls to be used, the vehicle's characteristics, guidance laws, etc. Namelist $TBLMLT is read once per phase if the end of phase variable switch is set to zero (ENDPHS = 0) in preceding $GENDAT. Otherwise it is not read. Namelist $TAB is read once per each table for that phase if ENDPHS = 0 is in $TBLMLT. Otherwise it is not read. Namelist $TAB is required for each table to be used in the problem. At the end of each phase's input for data (be it $GENDAT, $TBLMLT, $TAB) the variable ENDPHS must be set equal to one (ENDPHS = 1).

The following is a typical two phase problem. Three events are required since an event terminates on the minus side of the next event, i.e., no trajectory inputs are meaningful in the last event.

```
1$SEARCH
    :            Input data for targeting/optimization.
 $
1$GENDAT
    :            First phase general data.
 $
1$TBLMLT
    :            First phase table multipliers. Required for tables even if
    :            there are no multipliers.
 $
1$TAB
    :            Table One.
 $
1$TAB
    :            Table Two. ENDPHS = 1 must be set here.
 $
1$GENDAT
    :            Second phase data. No new tables, so ENDPHS = 1 set.
 $
```

1$GENDAT

:   No input data is meaningful in this phase. Set ENDPHS = 1,

:   ENDPRB = 1, and ENDJOB = 1.

$

C. Coordinate Systems

The first variables that should be identified is the set of coordinate systems that will be used for the problem. POST can compute in any coordinate system from earth centered rotating (XR, YR, ZR) to the orbital elements. These can be examined further in Reference 20, the POST Formulation Manual, Volume I. An equally important part of the coordinate system is the vehicles attitude angles and rates. For example, if the inertial launch axes (XL, YL, ZL) are chosen as the coordinate system, then the inertial euler angles (ROLI, YAWI, PITI) should be the attitude system chosen. With the many choices of coordinates and attitude angles available, an appropriate one can be found for any problem A careful scrutiny of Reference 20 will save time and aid in understanding when setting up a problem.

D. Targeting/Optimization Inputs

POST can perform targeting with or without inequality constraints, unconstrained optimization, and constrained (equality and/or inequality) optimization. The generality of POST allows the user to select the independent and dependent variables for the problem from a list of more than 400 program variables. All targeting/optimization inputs are made through namelist $SEARCH. The targeting/optimization mode is selected if the search mode flag (SRCHM) is set to "4" for projected gradient method or "5" for the accelerated projected gradient method. The maximum number of iterations is specified as MAXITR.

The control (independent) variables are specified by the number of independent variables (NINDV) that can range from 1 to 25; the indices of the active independent variables (INDXI); the names of the independent variables (INDVR); the event numbers at

which the controls are active (INDPH); the perturbations that are to be used to calculate the sensitivities (PERT); and the initial guesses for the control parameters (U).

Optimization is requested by input of OPT as nonzero and equal to "-1" for minimization and "+1" for maximization. The optimization variable is specified by the name of the optimization variable (OPTVAR) and the event at which the variable is to be optimized (OPTPH).

Targeting is requested by inputting the number of target (dependent) variables (NDEPV) as greater than zero and less than or equal to 25. The targets are specified by the indices of the active dependent variables (INDXD); the names of the dependent variables (DEPVR); the events at which the dependent variables are to be satisfied (DEPPH); the desired values of the dependent variables (DEPVAL); the tolerances for the dependent variables (DEPTL); and the types of constraints (IDEPVR); "-1" for a lower bound inequality, "0" for an equality, and "+1" for an upper bound inequality.

E. Trajectory Simulation Inputs.

There are numerous simulation options that are available through POST. The general simulation options that can be input include: aerodynamic inputs, aeroheating calculations, atmospheric model/winds, event criteria/phase definition inputs, gravitational inputs, initial position and velocity, numerical integration methods, propulsion/throttling inputs, vehicle/propellant weight inputs and methods of steering (guidance). The main points of these will be covered in enough detail to give the beginning user an idea of how to set up and run a simulation. For each of the simulation options, the program control array (NPC) may be kept at its default value or changed as the user desires. These variables are input in namelist $GENDAT.

Aerodynamic Inputs:

NPC(8) 0 = no aerodynamic coefficients.

Aeroheating Calculations:

NPC(15) 0 = do not calculate aeroheating rate (default).

Atmosphere Model/Winds Input:

NPC(5)	0 = no atmosphere.
	2 = 1962 U.S. standard atmosphere (default).
	3 = 1963 Patrick AFB atmosphere.
	4 = 1971 Vandenberg AFB atmosphere.
	5 = 1976 U.S. standard atmosphere.
NPC(6)	0 = No winds (default).

Event Criteria/Phase Definition Inputs:

EVENT(1)	The event sequence number for current phase. This must be input for each phase.
CRITR	The name of the event criterion variable (default is TIME). This variable will be monitored to initiate the corresponding phase. Any appropriate variable from the list of output variables can be used.
VALUE	The value of the event criterion variable at which event is to occur.

Gravitational Inputs:

NPC(16)	1 = The gravity model for a spherical planet of radius (RE) 20,925,741 feet and gravitational constant (MU) of 1.4076539E+16 feet^3/sec^2.

Initial Position and Velocity:

see Reference 22, POST Utilization Manual, Volume II.

Numerical Integration Methods:

NPC(2)	1 = Fourth order Runge-Kutta.
	2 = Variable step/order predictor-corrector Krogh.
	3 = Laplace conic integration (for integrating orbits about a spherical planet).
	4 = Encke perturbed conic integration (for integrating orbits about an oblate planet).

DT	Integration step size (default is 1.0 second).

Propulsion/Throttling Inputs:

NPC(9)	0 = No thrust. 1,2 = Rocket, jet, or ramjet engine. A rocket engine requires the input of a thrust table (TVC1T) for the engine and a vacuum specific impulse (ISPV(1) or ISP1T) based on the value of IWDF(1).
IWDF(1)	2 = Calculate flowrate or specific fuel consumption as a function of the vacuum thrust (THR1) and the constant specific impulse (ISPV(1). 3 = Calculate flowrate or specific fuel consumption as a function of the vacuum thrust (THR1) and the specific impulse table (ISP1T).
NENG	1 = the number of thrusting engines (default).
ISPV1	The vacuum specific impulse for the rocket engine. Variable input in $GENDAT, used if IWDF(1) = 2.
ISP1T	The table of specific impulse for the engine. This table is input in $TAB, used if IWDF(1) = 3.
TVC1T	The vacuum thrust table for the engine. Input in $TAB, program reads as THR1; used if IWDF(1) = 2.

Vehicle/Propellant Weight Inputs:

NPC(30)	0 = The N-stage weight calculation model. Works with NPC(9) = 1,2 to calculate the vehicle's and the propellant's changing weight.

Methods of Guidance (Steering):

IGUID(1)	1 = Inertial Euler angles. There are 14 types of guidance available. This option is the only one covered here. See Reference 22 for more details.

IGUID(2)	0 = Uses same steering option for each axis.
IGUID(4)	This option selects the functional relationship used to compute the angles. See Reference 22 for required variables required to be input.

V. OUTPUT FILES

The program can print as many as 198 output variables at each print time. The default print block of 90 variables is usually all that is required for most uses. The listing of these variables is available in Reference 22. The main output file contains the original input file as well as all the values of the variables at each event in the problem (see Appendix C). The frequency of the print interval can be controlled by the variable PINC input in $GENDAT. If PINC is input as zero, printouts will occur at the end of each integration step (100 lists of 90 variables if the default values are used for a simulation run of 100 seconds). Otherwise, PINC must be input as a multiple of the integration interval (DT). Additional output variables that can be obtained are in the conic print block. It is obtained by setting NPC(1) to two or three (2 or 3) and contains the values of the orbital elements for an elliptical or hyperbolic orbit.

The program can write the contents of the main trajectory print block to a file at a user specified interval (PRNC). This file contains just the values of the variables in the print block. These values are written on a file named *Profil* and contains the data in binary format. There is also a file that contains the data in ASCII format; this file is called *Profila*. The values from the main trajectory printout can be set to the ASCII file by setting the value of the variable PRNCA. Both of these variables (PRNC and PRNCA) can be zero for the write interval to be DT or must be set to a multiple of DT. These files are made especially for data manipulation and display.

APPENDIX B

POST INPUT DATA DECK

I. AEROGLIDE

```
c
c                                   John Nicholson
c                                   May 4
c                                   AeroGlide
l$search
c
 srchm      =    5,                 /activate optimization feature
 maxitr     =    50,                /max number of iterations
 ioflag     =    3,                 /metric units in-out
 opt        =    1.0,               /+1 for maximization
 optvar     =    6hinc  ,           /optimization variable, inclination
 optph      =    100.0,             /optimization phase
 wopt       =    0.1,               /weighting factor (1/ opt var)
 coneps(1)  =    89.5,              /convergence plane angle (default = 89.9)
c
 nindv      =    6,                 /number of control var
 indvr      =    6hbnkpc1, 6halppc2, 6hbnkpc2, 6halppc2, 6hbnkpc2,
 indph      =    60,     60,     60,     70,     70,
 u          =    80.0,   0.050,  -0.300,  0.010,  -0.100,
 pert       =    1.0e-02, 1.0e-04, 1.0e-03, 1.0e-04, 1.0e-03,
c
 indvr(6)   =    6hcritr ,
 indph(6)   =    70 ,
 u(6)       =    65.0,
 pert(6)    =    1.0e-02,
c
 ndepv      =    2,                 /number of target var
 depvr      =    6hwprop , 6haltito,
 depval     =    0.0, 300000.0,
 deptl      =    10.0,    100.0,
 depph      =    100.0,    90.0,
$
```

```
l$gendat
 maxtim      =    10000.0,      /10000 seconds
 altmin      =    40000.0,      /40 km
 prnca       =    100.0,        /print interval for ascii profila file
 pinc        =    500.0,        /print interval for output file
 prnt(91)    =    4halta, 4haltp, 3hinc, 6henergy, 5hvcirc, 4hmass,
 prnt(97)    =    6hgenv1 , 6hgenv2 , 6hgenv3 , 6hrgenv ,
 prnt(101)   =    6hxmax1 , 5hpstop,
c
 event       =    10,           /INITIALIZE 300 KM ORBIT
 fesn        =    100,          /final event number
 title       =    0h* Baseline with 5k Fuel *,
c
 npc(1)      =    1,            /conic calcs
 npc(2)      =    3,            /Laplace conic integration method
 npc(3)      =    5,            /initial position
       altp  =    300.0,        /perigee altitude
       alta  =    300.0,        /apogee altitude
       inc   =    0.0,          /inclination
 npc(5)      =    0,            /no atmosphere
 npc(8)      =    0,            /aerodynamic coeff = none
       sref  =    16.48,        /aero surface reference area
       lref  =    7.7,          /aero reference length
 npc(9)      =    0,            /propulsion type, no thrust
 npc(15)     =    1,            /aeroheating rate calculations
 npc(16)     =    1,            /spherical planet
 npc(30)     =    0,            /vehicle weight model to be used
       wgtsg =    50000.0,      /vehicle wt (N)
      wpropi =    5000.0,       /initial propellant wt (N)
 iguid       =    3, 0, 1,      /inertial aero angles guidance
 monx        =    6hheatrt,     /monitor variables
 endphs      =    1,
$
l$gendat
 event       =    20,           /DEORBIT IMPULSE
 critr       =    4htime,
 value       =    5.0,
c
 npc(2)      =    1,            /RK-4 integrator
 npc(9)      =    1,            /rocket engine
       ispv  =    300.0,        /isp value
       iwdf  =    2,            /use thrust and isp to calculate
      iengmf =    1,            /turn rocket engine on
```

```
 alppc(1)      =     180.0,          /turn vehicle over for retro firing
 $
l$tblmlt
 $
l$tab
  table        =     5htvc1t, 0, 15000.0,   /thrust table
 endphs        =     1,
 $
l$gendat
 event         =     30,             /STOP IMPULSE FIRING
 critr         =     4haltp  ,
 value         =     50.0,           /50 km perigee altitude
 tol           =     0.01,           /tolerance 10 m
 npc(2)        =     3,              /Laplace conic integration
 npc(9)        =     0,              /no thrust
        iengmf =     0,              /turn off engine
 alppc(1)      =     0.0,            /turn vehicle back over
 endphs        =     1,
 $
l$gendat
 event         =     40,             /TURN ON ATMOSPHERE & BEGIN GLIDE
 critr         =     6haltito,
 value         =     120000.0,
 prnca         =     50.0,
 pinc          =     30.0,
c
 npc(2)        =     1,              /RK-4 integrator
 npc(5)        =     5,              /1976 standard atmosphere
 npc(8)        =     2,              /aerocoeff, lift + drag in tables
 npc(9)        =     0,              /no thrust
 npc(15)       =     1,              /aeroheating on
 iguid         =     0, 1, 0,        /aero angles guidance, separate channels
 iguid (6)     =     1, 0, 1,        /bank and aoa polynomials
       alppc   =     15.0, 0.0,
       bnkpc   =     80.0, 0.0,
 $
l$tblmlt
 $
l$tab
 Table         =     6hcdt   , 1, 6halpha , 20, 1 , 1 , 1 ,    /drag coeff
 0.0, .0974, 2.0, .0889, 4.0 .0868, 6.0, .0911, 8.0, .1018,
 10.0, .1189, 11.0, .1298, 12.0, .1423, 13.0, .1564, 14.0, .1721,
 16.0, .2084, 18.0, .2509, 20.0, .2999, 22.0, .3553,
```

```
 24.0, .4170, 26.0, .4851, 28.0, .5596, 30.0, .6405, 35.,.8706,
 40.0, 1.1406,
 ixtrp          =       0, 0, 0, 0,      /no extrapolation
 $
!$tab
 Table = 6hclt   , 1, 6halpha ,  20 , 1 , 1 , 1 ,                  /lift coeff
 0.0, 0.0154, 2.0, .0509, 4., .0887, 6., .1287, 8., .1709,
 10., .2154, 11.0, .2385, 12.0, .2622, 13., .2864, 14., .3112,
 16., .3625, 18., .4160, 20., .4718, 22., .5298, 24., .5901,
 26., .6526, 28., .7174, 30., .7844, 35., .9619,
 40.0, 1.1534,
 ixtrp          =       0, 0, 0, 0,      /no extrapolation
 endphs         =       1,
 $
l$gendat
 event          =       60,              /BEGIN BOOST MANEUVER
 critr          =       6htdurp ,        /time as next criterion varaible
 value          =       180.0,           /
 prnca          =       10.0,
 pinc           =       10.0,
c
 npc(8)         =       2.               /aero coeff in tables
 npc(9)         =       1,               /rocket engine
        iwdf    =       2,               /calculate using isp and thrust
        ispv    =       300.0,           /isp
        iengmf  =       1,               /turn on rocket engine
 npc(15)        =       1,               /aeroheating
 iguid          =       0, 1, 0,         /aero angles guidance
 iguid (6)      =       0, 0, 1,         /set initial bank, carry over aoa
 $
l$tblmlt
 $
l$tab
 table          =       5htvclt, 0 , 15000.0 ,         /thrust table
 endphs         =       1,
 $
l$gendat
 event          =       70, 1.0,         /TURN OFF ENGINE
 critr          =       6htdurp ,
 value          =       500.0,           /not used
 prnca          =       20.0,
 pinc           =       50.0,
 npc(9)         =       0,
```

```
        iengmf =     0,               /turns off engine
 iguid         =     0, 0, 0,
 endphs        =     1,
 $
l$gendat
 event         =     80, 1.0,         /EXIT ATMOSPHERE
 critr         =     6haltito,
 value         =     120000.0,
c
 prnca         =     100.0,
 pinc          =     100.0,
 npc(2)        =     3,               /Laplace conic integration
 npc(5)        =     0,               /no atmosphere
 npc(8)        =     0,               /no aero coeff
 iguid         =     3, 0, 1,         /inertial aero angles guidance
   alppc(1)    =     0.0, 0.0, 0.0,
   bnkpc(1)    =     0.0, 0.0, 0.0,
 endphs        =     1,
 $
l$gendat
 event         =     90,              /CIRCULARIZE ORBIT
 critr         =     6haltito,
 value         =     300000.0,
 npc(9)        =     3,
        isdvin =     0.0,
 endphs        =     1,
 $
l$gendat
 event         =     100,             /END RUN
 critr         =     6htdurp ,
 value         =     5.0,
 endphs        =     1,
 endprb        =     1,
 endjob        =     1,
 $
```

II. AEROCRUISE

```
c
c                                       John Nicholson
c                                       May 8
c                                       AeroCruise
l$search
c
 srchm      =   5,              /activate optimization feature
 maxitr     =   30,             /max number of iterations
 ioflag     =   3,              /metric units in-out
 opt        =   1.0,            /+1 for maximization
 optvar     =   6hinc  ,        /optimization variable, inclination
 optph      =   100.0,          /optimization phase
 wopt       =   0.1,            /weighting factor (1/ opt var)
 coneps     =   89.5,
c
 nindv      =   7,              /number of control var
 indvr      =   6halppc2, 6halppc2, 6hbnkpc2, 6halppc2, 6hbnkpc2,
 indph      =   50,    60,    60,    70,    70,
 u          =   0.200,  -0.010,  -0.050,  0.010,  -0.020,
 pert       =   1.0e-04, 1.0e-04, 1.0e-04, 1.0e-04, 1.0e-04,
c
 indvr(6)   =   6hcritr , 6halppc1,
 indph(6)   =   70,    70,
 u(6)       =   150.0,   40.0,
 pert(6)    =   1.0e-02,   1e-3,
c
 ndepv      =   4,              /number of target var
 depvr      =   6hwprop , 6haltito, 6halppc1, 6hgammaa,
 depval     =   0.0, 300000.0,   39.0,    0.0,
 deptl      =   10.0,    100.0,  1.e-2,   1e-6,
 depph      =   100.0,    90.0,    70,    60.0,
 idepvr(3)  =   1,
$
l$gendat
 maxtim     =   10000.0,        /10000 seconds
 altmin     =   40000.0,        /40 km
 prnca      =   100.0,          /interval for profila file
 pinc       =   500.0,          /interval for output file
 prnt(91)   =   4halta, 4haltp, 3hinc, 6henergy, 5hvcirc, 4hmass,
 prnt(97)   =   6hgenv1 , 6hgenv2 , 6hgenv3 , 6hrgenv ,
 prnt(101)  =   6hxmax1 , 5hpstop,
c
```

```
 event          =    10,          /INITIALIZE 300 KM ORBIT
 fesn           =    100,         /final event number
 title          =    0h* Aerocruise with 20k N of Fuel *,
c
 npc(1)         =    1,           /conic calcs
 npc(2)         =    3,           /Laplace conic integration method
 npc(3)         =    5,           /initial position
      altp      =    300.0,       /perigee
      alta      =    300.0,       /apogee
      inc       =    0.0,         /inclination
 npc(5)         =    0,           /no atmosphere
 npc(8)         =    0,           /aerodynamic coeff = none
      sref      =    16.48,       /aero surface reference area
      lref      =    7.7,         /aero reference length
 npc(9)         =    0,           /propulsion type, no thrust
 npc(15)        =    1,           /aeroheating rate calculations
 npc(16)        =    1,           /spherical planet
 npc(30)        =    0,           /vehicle weight model to be used
      wgtsg     =    0000.0,      /vehicle wt (N)
      wpropi    =    20000.0,     /initial propellant wt (N)
 iguid          =    3, 0, 1,     /inertial aero angles guidance
 monx           =    6hheatrt,    /monitor variables
 endphs         =    1,
 $
l$gendat
 event          =    20,          /DEORBIT IMPULSE
 critr          =    4htime,
 value          =    5.0,
c
 npc(2)         =    1,           /RK-4 integrator
 npc(9)         =    1,           /rocket engine
      ispv      =    300.0,       /isp value
      iwdf      =    2,           /use thrust and isp to calculate
      iengmf    =    1,           /turn rocket engine on
 alppc(1)       =    180.0,       /turn vehicle over for retro firing
 $
l$tblmlt
 $
l$tab
 table          =    5htvc1t,0,15000.0,    /thrust table
 endphs         =    1,
 $
l$gendat
```

```
 event          =      30,            /STOP IMPULSE FIRING
 critr          =      4haltp  ,
 value          =      50.0,          /50 km perigee altitude
 tol            =      0.01,          /tolerance 10 m
c
 npc(2)         =      3,             /Laplace conic integration
 npc(9)         =      0,             /no thrust
         iengmf =      0,             /turn off engine
 alppc(1)       =      0.0,           /turn vehicle back over
 endphs         =      1,
 $
l$gendat
 event          =      40,            /ENTER ATMOSPHERE
 critr          =      6haltito,
 value          =      120000.0,
 prnca          =      30.0,
 pinc           =      30.0,
c
 npc(2)         =      1,             /RK-4 integrator
 npc(5)         =      5,             /1976 standard atmosphere
 npc(8)         =      2,             /aerocoeff, lift + drag in tables
 npc(9)         =      0,             /no thrust
 npc(15)        =      1,             /aeroheating on
 iguid          =      0, 1, 0,       /aero angles guidance, separate channels
 iguid (6)      =      1, 0, 1,       /bank and aoa polynomials
         alppc  =      15.0, 0.0,
         bnkpc  =      70.0, 0.0,
 $
l$tblmlt
 $
l$tab
 Table          =      6hcdt   , 1, 6halpha , 20, 1, 1, 1,          /drag coeff
 0.0, .0974, 2.0, .0889, 4.0, .0868, 6.0, .0911, 8.0, .1018,
 10.0, .1189, 11.0, .1298, 12.0, .1423, 13.0, .1564, 14.0, .1721,
 16.0, .2084, 18.0, .2509, 20.0, .2999, 22.0, .3553,
 24.0, .4170, 26.0, .4851, 28.0, .5596, 30.0, .6405, 35.,.8706,
 40.0, 1.1406,
 ixtrp          =      0, 0, 0, 0,    /no extrapolation
 $
l$tab
 table          =      6hclt   , 1, 6halpha ,   20, 1 , 1, 1,        /lift coeff
 0.0, 0.0154, 2.0, .0509, 4., .0887, 6., .1287, 8., .1709,
 10., .2154, 11.0, .2385, 12.0, .2622, 13., .2864, 14., .3112,
```

```
16., .3625, 18., .4160, 20., .4718, 22., .5298, 24., .5901,
26., .6526, 28., .7174, 30., .7844, 35., .9619,
40.0, 1.1534,
 ixtrp        =     0, 0, 0, 0,      /no extrapolation
 endphs       =     1,
 $
l$gendat
 event        =     50,              /BEGIN AEROCRUISE MANEUVER
 critr        =     6htdurp ,
 value        =     525.0,
 prnca        =     10.0,
 pinc         =     10.0,
c
 npc(8)       =     2,               /aero coeff fm tables
 npc(9)       =     1,               /rocket engine
      iwdf    =     2,               /calculate using isp and thrust
      ispv    =     300.0,           /isp
      iengmf  =     1,               /turn on rocket engine
 npc(15)      =     1,               /aeroheating calcs
 npc(22)      =     3,               /throttling parameter from table
 iguid        =     0, 1, 0,         /aero angles guidance
 iguid(6)     =     0, 0, 2,         /bank angle from tables
 $
l$tblmlt
 genv2m(2)    =     6hmass  ,
 genv3m(2)    =     6hthrust,
 genv5m       =     9.58, 6hmass  ,
 etam         =     6.6667e-05, 6hgenv6 ,
 $
l$tab
 table        =     6hgenv1t, 2, 6hlift  , 6hgenv3 , 11, 11, 1, 1, 1, 1, 1, 1, 1, 1,
    0.000,
    0.000,      0.000,    2000.000,    2000.000,   4000.000,    4000.000,
 6000.000,   6000.000,    8000.000,    8000.000,  10000.000,   10000.000,
12000.000,  12000.000,   14000.000,   14000.000,  16000.000,   16000.000,
18000.000,  18000.000,   20000.000,   20000.000,
 1500.000,
    0.000,   1500.000,    2000.000,    3500.000,   4000.000,    5500.000,
 6000.000,   7500.000,    8000.000,    9500.000,  10000.000,   11500.000,
12000.000,  13500.000,   14000.000,   15500.000,  16000.000,   17500.000,
18000.000,  19500.000,   20000.000,   21500.000,
 3000.000,
    0.000,   3000.000,    2000.000,    5000.000,   4000.000,    7000.000,
```

6000.000, 9000.000, 8000.000, 11000.000, 10000.000, 13000.000,
12000.000, 15000.000, 14000.000, 17000.000, 16000.000, 19000.000,
18000.000, 21000.000, 20000.000, 23000.000,
4500.000,
0.000, 4500.000, 2000.000, 6500.000, 4000.000, 8500.000,
6000.000, 10500.000, 8000.000, 12500.000, 10000.000, 14500.000,
12000.000, 16500.000, 14000.000, 18500.000, 16000.000, 20500.000,
18000.000, 22500.000, 20000.000, 24500.000,
6000.000,
0.000, 6000.000, 2000.000, 8000.000, 4000.000, 10000.000,
6000.000, 12000.000, 8000.000, 14000.000, 10000.000, 16000.000,
12000.000, 18000.000, 14000.000, 20000.000, 16000.000, 22000.000,
18000.000, 24000.000, 20000.000, 26000.000,
7500.000,
0.000, 7500.000, 2000.000, 9500.000, 4000.000, 11500.000,
6000.000, 13500.000, 8000.000, 15500.000, 10000.000, 17500.000,
12000.000, 19500.000, 14000.000, 21500.000, 16000.000, 23500.000,
18000.000, 25500.000, 20000.000, 27500.000,
9000.000,
0.000, 9000.000, 2000.000, 11000.000, 4000.000, 13000.000,
6000.000, 15000.000, 8000.000, 17000.000, 10000.000, 19000.000,
12000.000, 21000.000, 14000.000, 23000.000, 16000.000, 25000.000,
18000.000, 27000.000, 20000.000, 29000.000,
10500.000,
0.000, 10500.000, 2000.000, 12500.000, 4000.000, 14500.000,
6000.000, 16500.000, 8000.000, 18500.000, 10000.000, 20500.000,
12000.000, 22500.000, 14000.000, 24500.000, 16000.000, 26500.000,
18000.000, 28500.000, 20000.000, 30500.000,
12000.000,
0.000, 12000.000, 2000.000, 14000.000, 4000.000, 16000.000,
6000.000, 18000.000, 8000.000, 20000.000, 10000.000, 22000.000,
12000.000, 24000.000, 14000.000, 26000.000, 16000.000, 28000.000,
18000.000, 30000.000, 20000.000, 32000.000,
13500.000,
0.000, 13500.000, 2000.000, 15500.000, 4000.000, 17500.000,
6000.000, 19500.000, 8000.000, 21500.000, 10000.000, 23500.000,
12000.000, 25500.000, 14000.000, 27500.000, 16000.000, 29500.000,
18000.000, 31500.000, 20000.000, 33500.000,
15000.000,
0.000, 15000.000, 2000.000, 17000.000, 4000.000, 19000.000,
6000.000, 21000.000, 8000.000, 23000.000, 10000.000, 25000.000,
12000.000, 27000.000, 14000.000, 29000.000, 16000.000, 31000.000,
18000.000, 33000.000, 20000.000, 35000.000,

```
$
l$tab
table      =     6hgenv2t, 2, 6hgenv4 , 6hgammaa, 11, 11, 1,1,1,1,1,1,1,1,
 -2.000,
0.000,  0.00000,  0.500,  0.49970,  1.000,  0.99939,  1.500,  1.49909,
2.000,  1.99878,  2.500,  2.49848,  3.000,  2.99817,  3.500,  3.49787,
4.000,  3.99756,  4.500,  4.49726,  5.000,  4.99695,
 -1.500,
0.000,  0.00000,  0.500,  0.49983,  1.000,  0.99966,  1.500,  1.49949,
2.000,  1.99931,  2.500,  2.49914,  3.000,  2.99897,  3.500,  3.49880,
4.000,  3.99863,  4.500,  4.49846,  5.000,  4.99829,
 -1.000,
0.000,  0.00000,  0.500,  0.49992,  1.000,  0.99985,  1.500,  1.49977,
2.000,  1.99970,  2.500,  2.49962,  3.000,  2.99954,  3.500,  3.49947,
4.000,  3.99939,  4.500,  4.49931,  5.000,  4.99924,
 -0.500,
0.000,  0.00000,  0.500,  0.49998,  1.000,  0.99996,  1.500,  1.49994,
2.000,  1.99992,  2.500,  2.49990,  3.000,  2.99989,  3.500,  3.49987,
4.000,  3.99985,  4.500,  4.49983,  5.000,  4.99981,
 0.000,
0.000,  0.00000,  0.500,  0.50000,  1.000,  1.00000,  1.500,  1.50000,
2.000,  2.00000,  2.500,  2.50000,  3.000,  3.00000,  3.500,  3.50000,
4.000,  4.00000,  4.500,  4.50000,  5.000,  5.00000,
 0.500,
0.000,  0.00000,  0.500,  0.49998,  1.000,  0.99996,  1.500,  1.49994,
2.000,  1.99992,  2.500,  2.49990,  3.000,  2.99989,  3.500,  3.49987,
4.000,  3.99985,  4.500,  4.49983,  5.000,  4.99981,
 1.000,
0.000,  0.00000,  0.500,  0.49992,  1.000,  0.99985,  1.500,  1.49977,
2.000,  1.99970,  2.500,  2.49962,  3.000,  2.99954,  3.500,  3.49947,
4.000,  3.99939,  4.500,  4.49931,  5.000,  4.99924,
 1.500,
0.000,  0.00000,  0.500,  0.49983,  1.000,  0.99966,  1.500,  1.49949,
2.000,  1.99931,  2.500,  2.49914,  3.000,  2.99897,  3.500,  3.49880,
4.000,  3.99863,  4.500,  4.49846,  5.000,  4.99829,
 2.000,
0.000,  0.00000,  0.500,  0.49970,  1.000,  0.99939,  1.500,  1.49909,
2.000,  1.99878,  2.500,  2.49848,  3.000,  2.99817,  3.500,  3.49787,
4.000,  3.99756,  4.500,  4.49726,  5.000,  4.99695,
 2.500,
0.000,  0.00000,  0.500,  0.49952,  1.000,  0.99905,  1.500,  1.49857,
2.000,  1.99810,  2.500,  2.49762,  3.000,  2.99714,  3.500,  3.49667,
4.000,  3.99619,  4.500,  4.49572,  5.000,  4.99524,
```

```
 3.000,
 0.000,    0.00000,  0.500,   0.49931,  1.000,   0.99863,  1.500,   1.49794,
 2.000,    1.99726,  2.500,   2.49657,  3.000,   2.99589,  3.500,   3.49520,
 4.000,    3.99452,  4.500,   4.49383,  5.000,   4.99315,
$
l$tab
table      =      6hgenv3t, 1, 6halpha ,11, 1, 1, 1,
0.0, 0.0, 5.0, .0872, 10., .1736, 15., .2588, 20., .3420,
25., .4226, 30., .5000, 35.0, .5736, 40., .6428, 50., 0.766, 60., 0.866,
$
l$tab
table      =      6hgenv4t, 2, 6hvela  , 6haltito, 11, 8, 1, 1, 1, 1, 1, 1, 1, 1,
 50000.000,
  6500.000,    3.074,  6600.000,    2.870,  6700.000,    2.663,
  6800.000,    2.453,  6900.000,    2.240,  7000.000,    2.024,
  7100.000,    1.804,  7200.000,    1.582,  7300.000,    1.356,
  7400.000,    1.128,  7500.000,    0.896,
 60000.000,
  6500.000,    3.054,  6600.000,    2.851,  6700.000,    2.644,
  6800.000,    2.434,  6900.000,    2.222,  7000.000,    2.006,
  7100.000,    1.787,  7200.000,    1.564,  7300.000,    1.339,
  7400.000,    1.111,  7500.000,    0.880,
 70000.000,
  6500.000,    3.034,  6600.000,    2.831,  6700.000,    2.625,
  6800.000,    2.416,  6900.000,    2.203,  7000.000,    1.988,
  7100.000,    1.769,  7200.000,    1.547,  7300.000,    1.322,
  7400.000,    1.094,  7500.000,    0.863,
 80000.000,
  6500.000,    3.015,  6600.000,    2.812,  6700.000,    2.606,
  6800.000,    2.397,  6900.000,    2.185,  7000.000,    1.970,
  7100.000,    1.751,  7200.000,    1.530,  7300.000,    1.305,
  7400.000,    1.078,  7500.000,    0.847,
 90000.000,
  6500.000,    2.995,  6600.000,    2.793,  6700.000,    2.587,
  6800.000,    2.379,  6900.000,    2.167,  7000.000,    1.952,
  7100.000,    1.734,  7200.000,    1.513,  7300.000,    1.289,
  7400.000,    1.061,  7500.000,    0.831,
 100000.000,
  6500.000,    2.976,  6600.000,    2.774,  6700.000,    2.569,
  6800.000,    2.360,  6900.000,    2.149,  7000.000,    1.934,
  7100.000,    1.717,  7200.000,    1.496,  7300.000,    1.272,
  7400.000,    1.045,  7500.000,    0.815,
 110000.000,
```

```
 6500.000,      2.957,  6600.000,      2.755,  6700.000,      2.550,
 6800.000,      2.342,  6900.000,      2.131,  7000.000,      1.917,
 7100.000,      1.699,  7200.000,      1.479,  7300.000,      1.255,
 7400.000,      1.029,  7500.000,      0.799,
120000.000,
 6500.000,      2.938,  6600.000,      2.736,  6700.000,      2.532,
 6800.000,      2.324,  6900.000,      2.113,  7000.000,      1.899,
 7100.000,      1.682,  7200.000,      1.462,  7300.000,      1.239,
 7400.000,      1.013,  7500.000,      0.783,
$
l$tab
table       =     6hgenv5t, 1, 6hgammaa, 10, 1,1,1,
-2.0, -0.0349, -1.5, -0.0262, -1.0, -0.0175, -0.5, -0.0087, 0.0,
0.0, 0.5, 0.0087, 1.0, 0.0175, 1.5, 0.0262, 2.0, 0.0349,
2.5, 0.0436,
$
l$tab
table       =     6hgenv6t, 2, 6hdrag  , 6hgenv5 ,11, 6, 1,1,1,1,1,1,1,1,
 -2500.000,
   0.000,  -2500.0000, 1000.000,  -1500.0000, 2000.000,   -500.0000,
 3000.000,    500.0000, 4000.000,   1500.0000, 5000.000,   2500.0000,
 6000.000,   3500.0000, 7000.000,   4500.0000, 8000.000,   5500.0000,
 9000.000,   6500.0000, 10000.000,   7500.0000,
 -1500.000,
   0.000,  -1500.0000, 1000.000,   -500.0000, 2000.000,    500.0000,
 3000.000,   1500.0000, 4000.000,   2500.0000, 5000.000,   3500.0000,
 6000.000,   4500.0000, 7000.000,   5500.0000, 8000.000,   6500.0000,
 9000.000,   7500.0000, 10000.000,   8500.0000,
 -500.000,
   0.000,   -500.0000, 1000.000,    500.0000, 2000.000,   1500.0000,
 3000.000,   2500.0000, 4000.000,   3500.0000, 5000.000,   4500.0000,
 6000.000,   5500.0000, 7000.000,   6500.0000, 8000.000,   7500.0000,
 9000.000,   8500.0000, 10000.000,   9500.0000,
  500.000,
   0.000,    500.0000, 1000.000,   1500.0000, 2000.000,   2500.0000,
 3000.000,   3500.0000, 4000.000,   4500.0000, 5000.000,   5500.0000,
 6000.000,   6500.0000, 7000.000,   7500.0000, 8000.000,   8500.0000,
 9000.000,   9500.0000, 10000.000,  10500.0000,
 1500.000,
   0.000,   1500.0000, 1000.000,   2500.0000, 2000.000,   3500.0000,
 3000.000,   4500.0000, 4000.000,   5500.0000, 5000.000,   6500.0000,
 6000.000,   7500.0000, 7000.000,   8500.0000, 8000.000,   9500.0000,
 9000.000,  10500.0000, 10000.000,  11500.0000,
```

```
 2500.000,
   0.000,   2500.0000,  1000.000,   3500.0000,  2000.000,   4500.0000,
 3000.000,   5500.0000,  4000.000,   6500.0000,  5000.000,   7500.0000,
 6000.000,   8500.0000,  7000.000,   9500.0000,  8000.000,  10500.0000,
 9000.000,  11500.0000, 10000.000,  12500.0000,
$
l$tab
table        =     6hbankt , 1, 6hrgenv , 28, 1, 1, 1,
- 1.0, 180.0, -.8, 143.1, -.4, 113.6, -.2, 101.537, -.15, 98.6269,
 -.10, 95.739, -.05, 92.866, 0.0, 90.0,
.05, 87.134, .10, 84.261, .15, 81.373, .20, 78.463, .25, 75.5225,
.30, 72.542, .35, 69.513, .40, 66.422, .45, 63.256, .50, 60.0,
.55, 56.633, .60, 53.1301, .65, 49.458, .70, 45.573, .75, 41.410,
.80, 36.870, .85, 31.788, .90, 25.842, 1.0, 0.0, 1.0001, 90.0,
ixtrp        =     0,0,0,0,                /no extrapolation
$
l$tab
table        =     6htvclt , 1, 4heta , 2, 1, 1, 1,
0.0, 0.0, 1.0, 15000.0,
ixtrp        =     0,0,0,0,
$
l$tab
table        =     6hetat  , 1, 6halpha , 9, 1,1,1,
0.0, 1.0, 5., 1.0038, 10.0, 1.0154, 15.0, 1.0353, 20.0, 1.0642,
25.0, 1.1034, 30.0, 1.1547, 35.0, 1.2208, 40.0, 1.3054,
ixtrp        =     0,0,0,0,
endphs       =     1,
$
l$gendat
event        =     60,          /BEGIN BOOST MANEUVER
critr        =     6htdurp ,    /
value        =     105.0,             /
prnca        =     30.0,
pinc         =     30.0,
c
npc(8)       =     2,           /aero coeff in tables
npc(9)       =     1,           /rocket engine
      iwdf   =     2,           /calculate using isp and thrust
      ispv   =     300.0,       /isp
      iengmf =     1,           /turn on rocket engine
npc(15)      =     1,           /aeroheating
npc(22)      =     3,           /turn off throttling
iguid        =     0, 1, 0,     /aero angles guidance
```

```
 iguid(6)       =     0, 0, 0,
 $
l$tblmlt
 etam(1)        =     1.0,
 etam(2)        =     6hone  ,
 genv2m(2)      =     6hone  ,
 genv3m(2)      =     6hone  ,
 tvc1m(2)       =     6hone  ,
 $
l$tab
 table          =     4hetat, 0, 1.0,
 $
l$tab
  table         =     5htvc1t,0,15000.0,
 endphs         =     1,
 $
l$gendat
 event          =     70, 1.0,        /TURN OFF ENGINE
 critr          =     6htdurp ,
 value          =     90.0,           /not used
 tol            =     0.01,           /tolerance 10 m
 prnca          =     50.0,
 pinc           =     50.0,
c
 npc(9)         =     0,
        iengmf  =     0,              /turns off engine
 endphs         =     1,
 $
l$gendat
 event          =     80,1.0,         /EXIT ATMOSPHERE
 critr          =     6haltito,
 value          =     120000.0,
c
 prnca          =     100.0,
 pinc           =     500.0,
 npc(2)         =     3,              /Laplace conic integration
 npc(5)         =     0,              /no atmosphere
 npc(8)         =     0,              /no aero coeff
 iguid          =     3, 0, 1,        /inertial aero angles guidance
        alppc   =     0.0, 0.0, 0.0,
        bnkpc   =     0.0, 0.0, 0.0,
 endphs         =     1,
 $
```

```
l$gendat
 event        =    90,          /CIRCULARIZE ORBIT
 critr        =    6haltito,
 value        =    300000.0,
c
 npc(9)       =    3,
       isdvin =    0.0,
 endphs       =    1,
 $
l$gendat
 event        =    100,         /END RUN
 critr        =    6htdurp ,
 value        =    5.0,
c
 endphs       =    1,
 endprb       =    1,
 endjob       =    1,
 $
```

III. AEROBANG

```
c
c                                           John Nicholson
c                                           May 8
c                                           Aerobang
l$search
 srchm      =    5,               /activate optimization feature
 maxitr     =    30,              /max number of iterations
 ipro       =    0,               /
 ioflag     =    3,               /metric units in-out
 opt        =    1.0,             /+1 for maximization
 optvar     =    6hinc  ,         /optimization variable, inclination
 optph      =    100.0,           /optimization phase
 wopt       =    0.1,             /weighting factor (1/ opt var)
 coneps     =    89.5,
c
 nindv      =    7,               /number of control var
 indvr      =    6hbnkpc1, 6hbnkpc2, 6hbnkpc2, 6halppc2,
 indph      =    50,     50,     60,     60,
 u          =    92.0,  -0.210,  -0.210,   0.010,
 pert       =    1.0e-02, 1.0e-04, 1.0e-04, 1.0e-04,
c
 indvr(5)   =    6hcritr , 6hbnkpc2, 6halppc2,
 indph(5)   =    70,     70,     70,
 u(5)       =    171.0,   -0.040,   0.010,
 pert(5)    =    1.0e-02, 1.0e-04, 1.0e-04,
c
 ndepv      =    2,               /number of target var
 depvr      =    6hwprop ,  6haltito,
 depval     =    0.0,  300000.0,
 deptl      =    50.0,     100.0,
 depph      =    100.0,     90.0,
c
 $
l$gendat
 maxtim     =    10000.0,         /10000 seconds
 altmin     =    40000.0,         /40 km
 prnca      =    100.0,
 pinc       =    500.0,
 prnt(91)   =    4halta, 4haltp, 3hinc, 6henergy, 5hvcirc, 4hmass,
 prnt(97)   =    6hgenv1 , 6hgenv7 , 6hgenv3 , 6hrgenv ,
 prnt(101)  =    6hxmax1 , 5hpstop,
c
```

```
 event          =     10,              /INITIALIZE 300 KM ORBIT
 fesn           =     100,
 title          =     0h* Aerobang with 15k N of Fuel *,
c
 npc(1)         =     1,               /conic calcs
 npc(2)         =     3,               /Laplace conic integration method
 npc(3)         =     5,               /initial position
       altp     =     300.0,
       alta     =     300.0,
       inc      =     0.0,
 npc(5)         =     0,               /no atmosphere
 npc(8)         =     0,               /aerodynamic coeff = none
       sref     =     16.48,           /aero reference area
       lref     =     7.7,             /aero reference length
 npc(9)         =     0,               /propulsion type, no thrust
 npc(15)        =     1,               /aeroheating rate calculations
 npc(16)        =     1,               /spherical planet
 npc(30)        =     0,               /vehicle weight model to be used
       wgtsg    =     50000.0,         /vehicle wt (N)
       wpropi   =     15000.0,         /initial propellant wt (N)
 iguid          =     3, 0, 1,         /inertial aero angles guidance
 monx           =     6hheatrt,               /monitor variables
 endphs         =     1,
 $
l$gendat
 event          =     20,              /DEORBIT IMPULSE
 critr          =     4htime,
 value          =     5.0,
c
 npc(2)         =     1,               /RK-4 integrator
 npc(9)         =     1,               /rocket engine
       ispv     =     300.0,           /isp value
       iwdf     =     2,               /use thrust and isp to calculate
       iengmf   =     1,               /turn rocket engine on
 alppc(1)       =     180.0,           /turn vehicle over for retro firing
 $
l$tblmlt
 $
l$tab
  table         =     5htvc1t,0,15000.0,      /thrust table
 endphs         =     1,
 $
l$gendat
```

```
 event        =     30,            /STOP IMPULSE FIRING
 critr        =     4haltp ,
 value        =     50.0,          /50 km perigee altitude
 tol          =     0.01,          /tolerance 10 m
c
 npc(2)       =     3,             /Laplace conic integration
 npc(9)       =     0,             /no thrust
       iengmf =     0,             /turn off engine
 alppc(1)     =     0.0,           /turn vehicle back over
 endphs       =     1,
 $
l$gendat
 event        =     40,            /TURN ON ATMOSPHERE
 critr        =     6haltito,
 value        =     120000.0,
 prnca        =     50.0,
 pinc         =     30.0,
c
 npc(2)       =     1,             /RK-4 integrator
 npc(5)       =     5,             /1976 standard atmosphere
 npc(8)       =     2,             /aerocoeff, lift + drag in tables
 npc(9)       =     0,             /no thrust
 npc(15)      =     1,             /aeroheating on
c
 iguid        =     0, 1, 0,       /aero angles guidance, separate channels
 iguid (6)    =     1, 0, 1,       /bank and aoa polynomials
       alppc  =     15.0, 0.0,
       bnkpc  =     70.0, 0.0,
 $
l$tblmlt
 $
l$tab
 table        =     6hcdt   , 1, 6halpha , 20,1,1,1,
 0.0, .0974, 2.0, .0889, 4.0, .0868, 6.0, .0911, 8.0, .1018,
 10.0, .1189, 11.0, .1298, 12.0, .1423, 13.0, .1564, 14.0, .1721,
 16.0, .2084, 18.0, .2509, 20.0, .2999, 22.0, .3553,
 24.0, .4170, 26.0, .4851, 28.0, .5596, 30.0, .6405, 35.,.8706,
 40.0, 1.1406,
 ixtrp        =     0, 0, 0, 0,
 $
l$tab
 table        =     6hclt   , 1, 6halpha , 20,1,1,1,
 0.0, 0.0154, 2.0, .0509, 4., .0887, 6., .1287, 8., .1709,
```

```
10., .2154, 11.0, .2385, 12.0, .2622, 13., .2864, 14., .3112,
16., .3625, 18., .4160, 20., .4718, 22., .5298, 24., .5901,
26., .6526, 28., .7174, 30., .7844, 35., .9619,
40.0, 1.1534,
ixtrp      =    0, 0, 0, 0,
endphs     =    1,
$
l$gendat
event      =    50,              /BEGIN AEROBANG MANEUVER
critr      =    6htdurp ,
value      =    525.0,
prnca      =    10.0,
pinc       =    10.0,
c
npc(8)     =    2,               /aero coeff fm tables
npc(9)     =    1,               /rocket engine
      iwdf =    2,               /calculate using isp and thrust
      ispv =    300.0,           /isp
   iengmf  =    1,               /turn on rocket engine
npc(15)    =    1,               /aeroheating calcs
iguid      =    0, 1, 0,         /aero angles guidance
iguid(6)   =    2, 0, 1,         /aoa angle from tables
$
l$tblmlt
genv7m(1)  =    8.240, 6hdens  ,
genv6m(1)  =    2.238e-05,
genv4m(2)  =    4hmass,
genv3m(2)  =    5hgenv4,
$
l$tab
 table     =    5htvc1t,0,15000.0,
$
l$tab
table      =    6halphat, 2, 5hgenv7, 5hgenv3, 40, 23, 1,1,1,1,1,1,1,1,
-100000.0000,
  5000.000,  40.00,  10000.000,  40.00,  15000.000,  40.00,
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 65000.000,  40.00,  70000.000,  40.00,  75000.000,  40.00,
 80000.000,  40.00,  85000.000,  40.00,  90000.000,  40.00,
 95000.000,  40.00,  100000.000,  39.5510,  105000.000,  38.6392,
110000.000,  37.7868,  115000.000,  36.9876,  120000.000,  36.2361,
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-30000.0000,
5000.000, 40.00, 10000.000, 40.00, 15000.000, 40.00,
20000.000, 40.00, 25000.000, 40.00, 30000.000, 40.00,
35000.000, 40.00, 40000.000, 38.2666, 45000.000, 36.2462,
50000.000, 34.5096, 55000.000, 32.9945, 60000.000, 31.6563,
65000.000, 30.4618, 70000.000, 29.3863, 75000.000, 28.4103,
80000.000, 27.5189, 85000.000, 26.6997, 90000.000, 25.9432,
95000.000, 25.2411, 100000.000, 24.5868, 105000.000, 23.9749,
110000.000, 23.4005, 115000.000, 22.8596, 120000.000, 22.3489,
125000.000, 21.8653, 130000.000, 21.4063, 135000.000, 20.9697,
140000.000, 20.5534, 145000.000, 20.1557, 150000.000, 19.7752,
155000.000, 19.4103, 160000.000, 19.0599, 165000.000, 18.7229,
170000.000, 18.3984, 175000.000, 18.0853, 180000.000, 17.7830,
185000.000, 17.4906, 190000.000, 17.2075, 195000.000, 16.9331,

200000.000, 16.6669,
-25000.0000,
5000.000, 40.00, 10000.000, 40.00, 15000.000, 40.00,
20000.000, 40.00, 25000.000, 40.00, 30000.000, 40.00,
35000.000, 38.3675, 40000.000, 36.0992, 45000.000, 34.1837,
50000.000, 32.5360, 55000.000, 31.0974, 60000.000, 29.8256,
65000.000, 28.6896, 70000.000, 27.6658, 75000.000, 26.7361,
80000.000, 25.8860, 85000.000, 25.1043, 90000.000, 24.3816,
95000.000, 23.7103, 100000.000, 23.0842, 105000.000, 22.4979,
110000.000, 21.9471, 115000.000, 21.4280, 120000.000, 20.9372,
125000.000, 20.4720, 130000.000, 20.0300, 135000.000, 19.6090,
140000.000, 19.2072, 145000.000, 18.8229, 150000.000, 18.4547,
155000.000, 18.1012, 160000.000, 17.7613, 165000.000, 17.4340,
170000.000, 17.1183, 175000.000, 16.8133, 180000.000, 16.5183,
185000.000, 16.2326, 190000.000, 15.9556, 195000.000, 15.6867,
200000.000, 15.4252,
-20000.0000,
5000.000, 40.00, 10000.000, 40.00, 15000.000, 40.00,
20000.000, 40.00, 25000.000, 40.00, 30000.000, 38.4984,
35000.000, 35.9126, 40000.000, 33.7774, 45000.000, 31.9725,
50000.000, 30.4184, 55000.000, 29.0600, 60000.000, 27.8579,
65000.000, 26.7829, 70000.000, 25.8131, 75000.000, 24.9313,
80000.000, 24.1241, 85000.000, 23.3810, 90000.000, 22.6931,
95000.000, 22.0533, 100000.000, 21.4558, 105000.000, 20.8957,
110000.000, 20.3686, 115000.000, 19.8711, 120000.000, 19.4001,
125000.000, 18.9531, 130000.000, 18.5276, 135000.000, 18.1217,
140000.000, 17.7336, 145000.000, 17.3618, 150000.000, 17.0050,
155000.000, 16.6617, 160000.000, 16.3311, 165000.000, 16.0120,
170000.000, 15.7036, 175000.000, 15.4051, 180000.000, 15.1157,
185000.000, 14.8348, 190000.000, 14.5617, 195000.000, 14.2959,
200000.000, 14.0369,
-15000.0000,
5000.000, 40.00, 10000.000, 40.00, 15000.000, 40.00,
20000.000, 40.00, 25000.000, 38.6750, 30000.000, 35.6682,
35000.000, 33.2568, 40000.000, 31.2629, 45000.000, 29.5751,
50000.000, 28.1197, 55000.000, 26.8458, 60000.000, 25.7167,
65000.000, 24.7055, 70000.000, 23.7918, 75000.000, 22.9597,
80000.000, 22.1968, 85000.000, 21.4931, 90000.000, 20.8406,
95000.000, 20.2327, 100000.000, 19.6638, 105000.000, 19.1294,
110000.000, 18.6256, 115000.000, 18.1490, 120000.000, 17.6969,
125000.000, 17.2667, 130000.000, 16.8563, 135000.000, 16.4638,
140000.000, 16.0876, 145000.000, 15.7262, 150000.000, 15.3783,
155000.000, 15.0428, 160000.000, 14.7186, 165000.000, 14.4046,

```
170000.000,  14.1002,  175000.000,  13.8045,  180000.000,  13.5167,
185000.000,  13.2363,  190000.000,  12.9626,  195000.000,  12.6950,
200000.000,  12.4330,
-10000.0000,
5000.000,  40.00,  10000.000,  40.00,  15000.000,  40.00,
20000.000,  38.9266,  25000.000,  35.3339,  30000.000,  32.5653,
35000.000,  30.3408,  40000.000,  28.4976,  45000.000,  26.9343,
50000.000,  25.5835,  55000.000,  24.3985,  60000.000,  23.3460,
65000.000,  22.4012,  70000.000,  21.5455,  75000.000,  20.7642,
80000.000,  20.0461,  85000.000,  19.3819,  90000.000,  18.7644,
95000.000,  18.1873,  100000.000,  17.6458,  105000.000.  17.1354,
110000.000,  16.6526,  115000.000,  16.1943,  120000.000,  15.7579,
125000.000,  15.3411,  130000.000,  14.9419,  135000.000,  14.5584,
140000.000,  14.1893,  145000.000,  13.8329,  150000.000,  13.4881,
155000.000,  13.1538,  160000.000,  12.8288,  165000.000,  12.5123,
170000.000,  12.2033,  175000.000,  11.9010,  180000.000,  11.6047,
185000.000,  11.3136,  190000.000,  11.0269,  195000.000,  10.7439,
200000.000,  10.4640,
-5000.0000,
5000.000,  40.00,  10000.000,  40.00,  15000.000,  39.3138,
20000.000,  34.8489,  25000.000,  31.6014,  30000.000,  29.0915,
35000.000,  27.0686,  40000.000,  25.3873,  45000.000,  23.9566,
50000.000,  22.7163,  55000.000,  21.6244,  60000.000,  20.6511,
65000.000,  19.7740,  70000.000,  18.9763,  75000.000,  18.2450,
80000.000,  17.5698,  85000.000,  16.9425,  90000.000,  16.3562,
95000.000,  15.8055,  100000.000,  15.2857,  105000.000,  14.7929,
110000.000,  14.3238,  115000.000,  13.8755,  120000.000,  13.4455,
125000.000,  13.0315,  130000.000,  12.6316,  135000.000,  12.2439,
140000.000,  11.8670,  145000.000,  11.4991,  150000.000,  11.1389,
155000.000,  10.7850,  160000.000,  10.4361,  165000.000,  10.0906,
170000.000,  9.7472,  175000.000,  9.4044,  180000.000,  9.0603,
185000.000,  8.7132,  190000.000,  8.3605,  195000.000,  7.9993,
200000.000,  7.6257,
0.0000,
5000.000,  40.00,  10000.000,  39.9865,  15000.000,  34.0817,
20000.000,  30.1618,  25000.000,  27.2960,  30000.000,  25.0695,
35000.000,  23.2653,  40000.000,  21.7572,  45000.000,  20.4662,
50000.000,  19.3398,  55000.000,  18.3416,  60000.000,  17.4453,
65000.000,  16.6313,  70000.000,  15.8849,  75000.000,  15.1945,
80000.000,  14.5509,  85000.000,  13.9465,  90000.000,  13.3751,
95000.000,  12.8317,  100000.000,  12.3115,  105000.000,  11.8107,
110000.000,  11.3257,  115000.000,  10.8532,  120000.000,  10.3898,
125000.000,  9.9324,  130000.000,  9.4776,  135000.000,  9.0214,
```

```
 140000.000,     8.5594,  145000.000,     8.0856,  150000.000,     7.5920,
 155000.000,     7.0661,  160000.000,     6.4864,  165000.000,     5.8059,
 170000.000,     4.8654,  175000.000, 0      ,  180000.000, 0      ,
 185000.000, 0      ,  190000.000, 0      ,  195000.000, 0      ,  200000.000, 0      ,
  5000.0000,
  5000.000,   40.00,   10000.000,   32.6833,   15000.000,   27.7659,
  20000.000,   24.4664,   25000.000,   22.0273,   30000.000,   20.1099,
  35000.000,   18.5365,   40000.000,   17.2032,   45000.000,   16.0445,
  50000.000,   15.0165,   55000.000,   14.0884,   60000.000,   13.2374,
  65000.000,   12.4460,   70000.000,   11.7003,   75000.000,   10.9881,
  80000.000,   10.2988.   85000.000,    9.6216,   90000.000,    8.9447,
  95000.000,    8.2533,  100000.000,    7.5255,  105000.000,    6.7216,
 110000.000,     5.7420,  115000.000, 0      ,  120000.000, 0      ,
 125000.000, 0      ,  130000.000, 0      ,  135000.000, 0      ,  140000.000, 0      ,
 145000.000, 0      ,  150000.000, 0      ,  155000.000, 0      ,  160000.000, 0      ,
 165000.000, 0      ,  170000.000, 0      ,  175000.000, 0      ,  180000.000, 0      ,
 185000.000, 0      ,  190000.000, 0      ,  195000.000, 0      ,  200000.000, 0      ,
 10000.0000,
  5000.000,   29.3131,   10000.000,   22.8776,   15000.000,   19.1367,
  20000.000,   16.5287,   25000.000,   14.5142,   30000.000,   12.8454,
  35000.000,   11.3841,   40000.000,   10.0373,   45000.000,    8.7236,
  50000.000,    7.3331,   55000.000,    5.5565,   60000.000, 0      ,
  65000.000, 0      ,   70000.000, 0      ,   75000.000, 0      ,   80000.000, 0      ,
  85000.000, 0      ,   90000.000, 0      ,   95000.000, 0      ,  100000.000, 0      ,
 105000.000, 0      ,  110000.000, 0      ,  115000.000, 0      ,  120000.000, 0      ,
 125000.000, 0      ,  130000.000, 0      ,  135000.000, 0      ,  140000.000, 0      ,
 145000.000, 0      ,  150000.000, 0      ,  155000.000, 0      ,  160000.000, 0      ,
 165000.000, 0      ,  170000.000, 0      ,  175000.000, 0      ,  180000.000, 0      ,
 185000.000, 0      ,  190000.000, 0      ,  195000.000, 0      ,  200000.000, 0      ,
ixtrp      =     0,0,0,0,
$
l$tab
table      =     6hgenv3t, 1, 5hgenv5, 2, 1, 1, 1,
 0.0, 0.0, 10000.0, 10000.0,
$
l$tab
table      =     6hgenv4t, 1, 6hgammaa, 13, 1, 1, 1,
 -10.0000,   -0.17365,  -8.0000,   -0.13917,  -6.0000,   -0.10453,
 -4.0000,   -0.06976,  -2.0000,   -0.03490,  -0.5000,   -0.0087,
  0.0000,    0.00000,   0.5000,    0.0087,   2.0000,    0.03490,
  4.0000,    0.06976,   6.0000,    0.10453,   8.0000,    0.13917,
  10.0000,   0.17365,
$
```

```
l$tab
 table          =       6hgenv5t, 2, 6hgenv6 , 6haltito, 11, 4,
 1, 1, 1, 1, 1, 1, 1, 1,
  60000.000,
  1000.0000,   1009.61652,  1200.0000,   1209.61646,  1400.0000,   1409.61646,
  1600.0000,   1609.61646,  1800.0000,   1809.61646,  2000.0000,   2009.61646,
  2200.0000,   2209.61646,  2400.0000,   2409.61646,  2600.0000,   2609.61646,
  2800.0000,   2809.61646,  3000.0000,   3009.61646,
  80000.000,
  1000.0000,   1009.55701,  1200.0000,   1209.55701,  1400.0000,   1409.55701,
  1600.0000,   1609.55701,  1800.0000,   1809.55701,  2000.0000,   2009.55701,
  2200.0000,   2209.55713,  2400.0000,   2409.55713,  2600.0000,   2609.55713,
  2800.0000,   2809.55713,  3000.0000,   3009.55713,
 100000.000,
  1000.0000,   1009.49811,  1200.0000,   1209.49805,  1400.0000,   1409.49805,
  1600.0000,   1609.49805,  1800.0000,   1809.49805,  2000.0000,   2009.49805,
  2200.0000,   2209.49805,  2400.0000,   2409.49805,  2600.0000,   2609.49805,
  2800.0000,   2809.49805,  3000.0000,   3009.49805,
 120000.000,
  1000.0000,   1009.43976,  1200.0000,   1209.43970,  1400.0000,   1409.43970,
  1600.0000,   1609.43970,  1800.0000,   1809.43970,  2000.0000,   2009.43970,
  2200.0000,   2209.43970,  2400.0000,   2409.43970,  2600.0000,   2609.43970,
  2800.0000,   2809.43970,  3000.0000,   3009.43970,
 $
l$tab
 table          =       6hgenv6t, 1, 4hvela, 5, 1, 1, 1,
  6000.0000, 36000000.000,  6500.0000, 42250000.000,
  7000.0000, 49000000.000,  7500.0000, 56250000.000,
  8000.0000, 64000000.000,
 $
l$tab
 table          =       6hgenv7t, 1, 4hvela, 5, 1, 1, 1,
  6000.0000, 36000000.000,  6500.0000, 42250000.000,
  7000.0000, 49000000.000,  7500.0000, 56250000.000,
  8000.0000, 64000000.000,
 endphs         =       1,
 $
l$gendat
 event          =       60,             /BEGIN BOOST MANEUVER
 critr          =       6htdurp ,       /
 value          =       75.0,           /adjust length of heat control?
 prnca          =       20.0,
 pinc           =       10.0,
```

```
c
 npc(8)        =    2,              /aero coeff in tables
 npc(9)        =    1,              /rocket engine
       iwdf    =    2,              /calculate using isp and thrust
       ispv    =    300.0,          /isp
       iengmf  =    1,              /turn on rocket engine
 npc(15)       =    1,              /aeroheating
 iguid         =    0, 1, 0,        /aero angles guidance
 iguid(6)      =    0, 0, 0,
 $
l$tblmlt
 genv2m(2)     =    6hone  ,
 genv3m(2)     =    6hone  ,
 tvc1m(2)      =    6hone  ,
 $
l$tab
  table        =    5htvc1t, 0, 15000.0,
 endphs        =    1,
 $
l$gendat
 event         =    70, 1.0,        /TURN OFF ENGINE
 critr         =    6htdurp ,
 value         =    50.0,           /not used
 prnca         =    50.0,
 pinc          =    50.0,
c
 npc(9)        =    0,
       iengmf  =    0,              /turns off engine
 endphs        =    1,
 $
l$gendat
 event         =    80, 1.0,        /EXIT ATMOSPHERE
 critr         =    6haltito,
 value         =    120000.0,
c
 prnca         =    100.0,
 pinc          =    100.0,
 npc(2)        =    3,              /Laplace conic integration
 npc(5)        =    0,              /no atmosphere
 npc(8)        =    0,              /no aero coeff
 iguid         =    3, 0, 1,        /inertial aero angles guidance
       bnkpc   =    0.0,0.0,0.0,
       alppc   =    0.0,0.0,0.0,
```

```
 endphs      =     1,
 $
l$gendat
 event       =     90,          /CIRCULARIZE ORBIT
 critr       =     6haltito,
 value       =     300000.0,
c
 npc(9)      =     3,
        isdvin =   0.0,
 endphs      =     1,
 $
l$gendat
 event       =     100,         /END RUN
 critr       =     6htdurp ,
 value       =     5.0,
c
 endphs      =     1,
 endprb      =     1,
 endjob      =     1,
$
```

APPENDIX C

POST OUTPUT EXAMPLE

```
1execution date and time Tue May 10 13:36:46 1994
page    1
                                                        problem no.   1



                     *** core requirements for problem   1 are ***

                       parameter          octal  decimal
                       event criteria data -  67b      55
                       general data     -  1522b    850
                       table data       -  176b     126


cpu time required for initialization =      2.480
1execution date and time Tue May 10 13:36:46 1994
page    2
                                                        problem no.   1


*** targeting/optimization inputs ***

    nindv  =  7        ndepv  =  2        srchm  =  5        modew  =  1
    indvr  =    bnkpc1 ,    alppc1 ,    alppc2 ,    bnkpc2 ,    alppc2 ,
bnkpc2  ,
             critr   ,
    indph  =  40.000,      40.000,      60.000,      60.000,      70.000,
70.000,
           70.000,
    u      = 8.00000000E+01, 1.50000000E+01, 1.50000000E-02,-2.00000000E-01,
3.00000000E-02,-4.00000000E-02,
          1.50000000E+02,
    wvu    = 1.25000000E-02, 6.66666667E-02, 6.66666667E+01, 5.00000000E+00,
3.33333333E+01, 2.50000000E+01,
          6.66666667E-03,
```

pert = 1.00000000E-02, 1.00000000E-03, 1.00000000E-04, 1.00000000E-04,
1.00000000E-04, 1.00000000E-03,
1.00000000E-02,
depvr = wprop , altito ,
depph = 100.000, 90.000,
depval = 0.00000000E+00, 3.00000000E+05,
deptl = 1.00000000E+01, 1.00000000E+02,
idepvr = 0, 0,
ifdeg = 0, 0,
optvar = inc ,
optph = 100.000,
opt = 1 maxitr = 50 ideb = 0 ipro = 0
itopf = 0 isens = 0
pgeps = 1.00000000E+00 p2min = 1.00000000E+00 stmnp1 = 1.00000000E-01
stmnp2 = 1.00000000E-01
consx1 = 1.00000000E-06 consx2 = 1.00000000E-03 fiter1 = 1.00000000E-06
fiter2 = 1.00000000E-03
pctcc = 3.00000000E-01 wopt = 1.00000000E-01 conep1 = 8.95000000E+01
conep2 = 1.00000000E-05
conep3 = 1.00000000E-05 conep4 = 1.00000000E-05 conep5 = 1.00000000E-05
conep6 = 1.00000000E-05
gamax = 1.00000000E+01 stpmax = 1.00000000E+10 pdlmax =
2.00000000E+00 npad1 = 9.00000000E+00
npad2 = 4.00000000E+00 npad3 = 1.44494398E+01
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page 3
baseline with 10k fuel problem
no. 1

input units = metric, output units = metric

initial state vector conditions
inc = 0.00000000E+00, altp = 3.00000000E+02, alta = 3.00000000E+02,
truan = 0.00000000E+00,
argp = 0.00000000E+00, lan = 0.00000000E+00,

program termination parameters
fesn = 100.000, maxtim = 1.00000000E+04, altmin = 4.00000000E+04,
altmax = 1.00000000E+20,

the launch pad inertial (l) frame is defined by
latl = 0.00000000E+00, lonl = 0.00000000E+00, azl = 0.00000000E+00,

attracting planet model
re = 6.37816586E+06, rp = 6.37816586E+06, omega = 7.29211000E-05,
mu = 3.98603195E+14,
j2 = 0.00000000E+00, j3 = 0.00000000E+00, j4 = 0.00000000E+00, j5
= 0.00000000E+00,
j6 = 0.00000000E+00, j7 = 0.00000000E+00, j8 = 0.00000000E+00,

1execution date and time Tue May 10 13:36:46 1994
page 48
baseline with 10k fuel problem
no. 1

*** nominal function evaluation

```
indvr  bnkpc1      alppc1      alppc2      bnkpc2      alppc2
bnkpc2
       critr
indph  40.000      40.000      60.000      60.000      70.000
70.000
       70.000
u(i)  8.00000000E+01   1.50000000E+01   1.50000000E-02   -2.00000000E-
01   3.00000000E-02   -4.00000000E-02
     1.50000000E+02


u= 8.000000000000E+01, 1.500000000000E+01, 1.500000000000E-02,
  -2.000000000000E-01, 3.000000000000E-02,-4.000000000000E-02,
   1.500000000000E+02,


we(i) -2.26729080E+02    -1.38059258E-07
depvr  wprop        altito
depph  100.000      90.000
e(i) -2.26729080E+03    -1.38059258E-05
p1   -6.06361774E-01

optvar  inc
optph  100.000
optvl 6.06361774E+00
p2   5.14060757E+04
```

*** trajectory terminated by altmin = 4.00000000E+04 ft ***
1execution date and time Tue May 10 13:36:46 1994
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baseline with 10k fuel problem
no. 1

*** iteration number 1

pert 2.77525993E-05 2.83718864E-05 8.91292775E-05 1.28624925E-06
2.54987801E-05 1.13001110E-04
5.29413011E-04
du 9.99095528E-01 1.94007760E-01 1.99653201E-02 5.03470372E-02
4.28619709E-04 1.11021876E-04
-3.64654188E-01
partials of wprop with respect to u(i)
smat 6.30707640E+02 7.11416445E+02 3.14404861E+04
1.37880911E+04 7.89187270E+02 1.51847451E+02
-1.34130739E+02
partials of altito with respect to u(i)
smat 7.12880865E-04 -4.41633165E-03 -3.43731139E+01 -1.33384019E-01 -2.17929482E-03 -1.61305070E-03
4.93973494E-04
g1(i) -2.85433559E+00 -4.54539992E-01 -2.19851901E-02 -1.52156156E-01 -1.01452852E-03 -3.57975199E-04
-6.92776806E-02
g1mag 2.89521565E+00
g2(i) -2.28799621E+06 -4.83896388E+05 -2.13854174E+04 -1.25043449E+05 -1.07359022E+03 -2.75425863E+02
9.12340169E+05
g2mag 2.51347213E+06
pg1(i)-4.06146507E-01 3.38530172E-02 -1.92770966E-01 -2.95342013E-02 9.96550181E-05 -9.00523388E-05
-1.00915853E+00
pg1mag 1.10568300E+00
wvu 1.25000000E-02 6.66666667E-02 6.66666667E+01
5.00000000E+00 3.33333333E+01 2.50000000E+01
6.66666667E-03
nac 2
iac 1 2
dp1ds -2.66588564E+00
dp2ds -2.51329861E+06

stpmax 1.00000000E+10
umag 2.65130090E+00
dumag 4.09072566E-02
step 0.00000000E+00 2.04536283E-02 2.04536283E-02
0.00000000E+00 0.00000000E+00 0.00000000E+00
p1try -6.06361774E-01 -6.65820566E-01 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00
p2try 5.14060757E+04 6.16377283E+03 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00
yes 0.00000000E+00 0.00000000E+00 -5.57760306E+04
0.00000000E+00 0.00000000E+00 0.00000000E+00
indvr bnkpc1 alppc1 alppc2 bnkpc2 alppc2
bnkpc2
critr
indph 40.000 40.000 60.000 60.000 70.000
70.000
70.000
u(i) 8.14875442E+01 1.50595224E+01 1.50061254E-02 -1.99794044E-
01 3.00002630E-02 -3.99999092E-02
1.48881225E+02

u= 8.148754416253E+01, 1.505952243911E+01, 1.500612544855E-02,
-1.997940440829E-01, 3.000026300485E-02,-3.999990916799E-02,
1.488812248159E+02,

we(i) -7.85096990E+01 -9.49390233E-08
depvr wprop altito
depph 100.000 90.000
e(i) -7.85096990E+02 -9.49390233E-06
p1 -6.65820566E-01

optvar inc
optph 100.000
optvl 6.65820566E+00
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p2 6.16377283E+03

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*** iteration number 2

pert 1.14181038E-05 1.19957695E-05 2.68843762E-07 5.01624898E-07
9.43624495E-06 3.88550179E-05
2.80057327E-04
du -1.95214682E-01 -2.70209079E-02 1.19396149E-01 -5.80392607E-02
6.51466430E-04 -3.38144125E-04
-9.71358103E-01
partials of wprop with respect to u(i)
smat 1.19491879E+03 1.30457265E+03 5.61542505E+04
2.81042376E+04 1.60387339E+03 3.68546576E+02
-1.90790899E+02
partials of altito with respect to u(i)
smat -3.14103166E-02 -3.41057391E-02 2.74096109E-01 -7.89226200E-
01 -3.67433464E-02 -1.13570788E-02
3.52711725E-03
g1(i) -3.38817108E+00 -5.27191446E-01 -2.43650099E-02 -1.86595746E-
01 -1.38597204E-03 -4.74324104E-04
-6.61449490E-02
g1mag 3.43473769E+00
g2(i) -1.50100343E+06 -3.07264817E+05 -1.32259599E+04 -
8.82582095E+04 -7.55517700E+02 -2.31475846E+02
4.49368081E+05
g2mag 1.59916218E+06
pg1(i)-3.66110214E-02 1.45639675E-01 -1.18883299E-01 5.81628755E-
02 -4.66879900E-04 3.58035031E-04
-1.47820572E-02
pg1mag 2.00714464E-01
nac 2
iac 1 2
dp1ds 7.47836412E-01
dp2ds -1.31633947E+05
stpmax 1.00000000E+10
umag 2.62192943E+00
dumag 9.36502014E-02

step 0.00000000E+00 9.36502014E-02 8.97292927E-02 7.92707467E-02
7.80367299E-02 7.96860981E-02
p1try -6.65820566E-01 -6.01293170E-01 -6.03787858E-01 -6.10525658E-01 -6.11328778E-01 -6.10255732E-01
p2try 6.16377283E+03 2.69338918E+02 1.37098920E+02 2.32901074E-01 3.56600336E+00 6.24484675E-05
yes 0.00000000E+00 0.00000000E+00 2.58062345E+02 -7.93787464E+00 1.30873838E+00 6.23449942E-03
indvr bnkpc1 alppc1 alppc2 bnkpc2 alppc2 bnkpc2
critr
indph 40.000 40.000 60.000 60.000 70.000 70.000
70.000
u(i) 8.02430725E+01 1.50272246E+01 1.51488386E-02 -2.00719029E-01 3.00018204E-02 -4.00009870E-02
1.37270664E+02

u= 8.024307245982E+01, 1.502722457837E+01, 1.514883864771E-02,
-2.007190285271E-01, 3.000182038938E-02,-4.000098698343E-02,
1.372706642610E+02,

we(i) -7.90243424E-03 -7.50375912E-07
depvr wprop altito
depph 100.000 90.000
e(i) -7.90243424E-02 -7.50375912E-05
p1 -6.10255732E-01

optvar inc
optph 100.000
optvl 6.10255732E+00
p2 6.24484675E-05
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baseline with 10k fuel problem no. 1

*** trajectory terminated by altmin = 4.00000000E+04 ft ***

*** trajectory terminated by altmin = 4.00000000E+04 ft ***

*** trajectory terminated by altmin = 4.00000000E+04 ft ***

*** trajectory terminated by altmin = 4.00000000E+04 ft ***

*** trajectory terminated by altmin = 4.00000000E+04 ft ***

*** trajectory terminated by altmin = 4.00000000E+04 ft ***

*** trajectory terminated by altmin = 4.00000000E+04 ft ***
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baseline with 10k fuel problem
no. 1

-*** trial step
gamas 3.99434562E-01
du 2.05471013E-01 -9.36527184E-01 2.79763193E-03 -2.83664431E-01
2.16161899E-03 -2.65827018E-03
-1.46089570E-02
wu(i) 1.08511063E+00 6.27733647E-01 1.01104005E+00 -
1.11690052E+00 1.00092410E+00 -1.00108648E+00
9.09302439E-01
indvr bnkpc1 alppc1 alppc2 bnkpc2 alppc2
bnkpc2
critr
indph 40.000 40.000 60.000 60.000 70.000
70.000
70.000
u(i) 8.68088504E+01 9.41600470E+00 1.51656007E-02 -2.23380104E-
01 3.00277231E-02 -4.00434592E-02
1.36395366E+02

u= 8.680885037416E+01, 9.416004701637E+00, 1.516560071098E-02,
-2.233801040938E-01, 3.002772314937E-02,-4.004345918284E-02,
1.363953659080E+02,

we(i) -7.90243424E-02 -7.50375912E-06

depvr wprop altito
depph 100.000 90.000
e(i) -7.90243424E-01 -7.50375912E-04
p1 4.88204586E+00

optvar inc
optph 100.000
optvl 6.28058188E+00
p2 6.24484675E-03

error *fgama* too many crashes

*** trajectory terminated by altmin = 4.00000000E+04 ft ***
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baseline with 10k fuel problem
no. 1

-*** trial step
gamas 3.96361988E-01
du 2.05471013E-01 -9.36527184E-01 2.79763193E-03 -2.83664431E-01
2.16161899E-03 -2.65827018E-03
-1.46089570E-02
wu(i) 1.08447930E+00 6.30611195E-01 1.01103145E+00 -
1.11602894E+00 1.00091746E+00 -1.00107831E+00
9.09347326E-01
indvr bnkpc1 alppc1 alppc2 bnkpc2 alppc2
bnkpc2
critr
indph 40.000 40.000 60.000 60.000 70.000
70.000
70.000
u(i) 8.67583444E+01 9.45916793E+00 1.51654718E-02 -2.23205788E-
01 3.00275239E-02 -4.00431325E-02
1.36402099E+02

u= 8.6758344390 20E+01, 9.459167931458E+00, 1.516547177203E-02,
-2.232057881279E-01, 3.002752389737E-02,-4.004313247361E-02,

1.364020989722E+02,

we(i) -7.90243424E-02 -7.50375912E-06
depvr wprop altito
depph 100.000 90.000
e(i) -7.90243424E-01 -7.50375912E-04
p1 4.88204586E+00

optvar inc
optph 100.000
optvl 6.28231708E+00
p2 6.24484675E-03

error *fgama* too many crashes

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baseline with 10k fuel problem
no. 1

*** iteration number 3

pert 5.88424431E-05 7.09016165E-05 1.54496734E-06 2.78073875E-06
3.45305431E-05 1.34875396E-04
5.71332332E-03
du 2.35609878E-01 2.31929539E-02 -3.17987291E-03 4.40662657E-02
-6.01965395E-04 3.71463133E-04
9.70565621E-01
partials of wprop with respect to u(i)
smat 1.19453259E+03 1.32339633E+03 5.63838606E+04
2.66275218E+04 2.59487250E+03 5.56924215E+02
-2.11644071E+02
partials of altito with respect to u(i)
smat -1.47796564E-01 -1.62184915E-01 -6.65814960E+00 -
3.43473135E+00 -2.97075899E-01 -7.60781493E-02
1.98497375E-02
g1(i) -2.94762117E+00 -4.58677525E-01 -2.10496220E-02 -1.55934482E-
01 -1.88360721E-03 -6.42983429E-04
-5.69212739E-02
g1mag 2.98778485E+00

g2(i) 5.88015956E+05 1.22146860E+05 5.20411862E+03
3.27689001E+04 4.79003181E+02 1.37074671E+02
-1.95343284E+05
g2mag 1.62438392E+02
pg1(i)-2.69338311E-02 1.22763132E-01 -3.66722999E-04 3.71836873E-
02 -2.83352284E-04 3.48454992E-04
1.91499120E-03
pg1mag 1.31083362E-01
nac 2
iac 1 2
ctha 8.74854498E+01
dp1ds -1.31083362E-01
dp2ds -5.11890530E-12
stpmax 1.00000000E+10
umag 2.62192943E+00
pctcc 3.00000000E-01
step 0.00000000E+00 3.93289415E-01 3.94825701E-01 2.83232582E-01
3.49949295E-01 3.80928462E-01
p1try -6.10166315E-01 -6.59433921E-01 -6.57973550E-01 -6.31710983E-
01 -6.43479807E-01 -6.47208327E-01
p2try 6.24484675E-05 9.46547141E+02 9.94960903E+02 4.74988989E-
01 1.70597886E+02 6.12470014E+02
yes 0.00000000E+00 0.00000000E+00 -9.00813368E-01 -7.06709411E-
01 -6.79674420E-01 -6.64651786E-01
nac 2
iac 1 2
dp1ds -7.67176203E-01
dp2ds 0.00000000E+00
stpmax 1.00000000E+10
umag 2.60064012E+00
dumag 4.04585607E-02
step 0.00000000E+00 4.04585607E-02 5.05732009E-02
0.00000000E+00 0.00000000E+00 0.00000000E+00
p1try -6.28395076E-01 -6.60903081E-01 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00
p2try 9.46547141E+02 8.55045837E-01 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00
yes 0.00000000E+00 0.00000000E+00 -9.00813368E-01 -7.06709411E-
01 -6.79674420E-01 -6.64651786E-01
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baseline with 10k fuel problem
no. 1

indvr bnkpc1 alppc1 alppc2 bnkpc2 alppc2
bnkpc2
critr
indph 40.000 40.000 60.000 60.000 70.000
70.000
70.000
u(i) 8.74704333E+01 9.51640646E+00 1.51634130E-02 -2.22674901E-
01 3.00265940E-02 -4.00422046E-02
1.42298985E+02

u= 8.747043333072E+01, 9.516406464296E+00, 1.516341303686E-02,
-2.226749006251E-01, 3.002659400577E-02,-4.004220460984E-02,
1.422989852531E+02,

we(i) -9.24686886E-01 -1.68570690E-05
depvr wprop altito
depph 100.000 90.000
e(i) -9.24686886E+00 -1.68570690E-03
p1 -6.60903081E-01

optvar inc
optph 100.000
optvl 6.60903081E+00
p2 8.55045837E-01

*** trajectory terminated by altmin = 4.00000000E+04 ft ***
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baseline with 10k fuel problem
no. 1

*** iteration number 4

pert 2.88681989E-05 3.46788950E-05 7.58445126E-07 1.11148232E-06
1.42084799E-05 4.67086987E-05
2.62683860E+00
du 7.44141588E-03 1.78013893E-02 -1.03345543E-04 1.09383783E-01
1.78496337E-03 1.05245859E-03

-9.93810153E-01
partials of wprop with respect to u(i)
smat 1.47675604E+03 1.23357146E+03 5.63671139E+04
4.98649215E+04 4.44379150E+03 1.52521653E+03
-2.43114476E+02
partials of altito with respect to u(i)
smat 2.84503910E+01 2.36016060E+01 1.07984705E+03
5.68376502E+02 3.90290034E+01 1.05222673E+01
2.37700237E-01
g1(i) -3.44408759E+00 -7.39269119E-01 -3.79796097E-02 -2.76662760E-01 -5.27188205E-03 -1.37354800E-03
2.28862331E-04
g1mag 3.53359202E+00
g2(i) -1.69048377E+05 -2.64769427E+04 -1.20984385E+03 -1.42704411E+04 -1.90759946E+02 -8.72978920E+01
5.21812332E+04
g2mag 2.31944270E+04
pg1(i) 2.86227613E-02 -1.98880188E-01 -1.32570804E-02 -9.59349934E-02 -3.35564239E-03 -6.61311316E-04
-1.39125143E-02
pg1mag 2.23510895E-01
nac 2
iac 1 2
ctha 8.63757053E+01
dp1ds -1.17138119E-01
dp2ds 5.74197796E+02
stpmax 1.00000000E+10
umag 2.60064012E+00
pctcc 3.00000000E-01
step 0.00000000E+00 1.95048009E-01 1.95048009E-01
0.00000000E+00 0.00000000E+00 0.00000000E+00
p1try -6.60921339E-01 -6.72692273E-01 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00
p2try 8.55045837E-01 5.11875721E+01 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00
yes 0.00000000E+00 0.00000000E+00 -6.72703153E-01
0.00000000E+00 0.00000000E+00 0.00000000E+00
nac 2
iac 1 2
dp1ds -6.92857012E-02
dp2ds 0.00000000E+00
stpmax 1.00000000E+10
umag 2.61085602E+00

dumag 1.85634444E-03
step 0.00000000E+00 1.85634444E-03 2.32043054E-03
0.00000000E+00 0.00000000E+00 0.00000000E+00
p1try -6.72569145E-01 -6.72623299E-01 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00
p2try 5.11875721E+01 2.25612350E-02 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00
yes 0.00000000E+00 0.00000000E+00 -6.72703153E-01
0.00000000E+00 0.00000000E+00 0.00000000E+00
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baseline with 10k fuel problem
no. 1

indvr bnkpc1 alppc1 alppc2 bnkpc2 alppc2
bnkpc2
critr
indph 40.000 40.000 60.000 60.000 70.000
70.000
70.000
u(i) 8.44908079E+01 1.22161987E+01 1.52160687E-02 -2.09621423E-
01 3.00478042E-02 -4.00205023E-02
1.42785410E+02

u= 8.449080794026E+01, 1.221619870305E+01, 1.521606873665E-02,
-2.096214234974E-01, 3.004780424820E-02,-4.002050233169E-02,
1.427854099585E+02,

we(i) -1.50203977E-01 -1.51499175E-05
depvr wprop altito
depph 100.000 90.000
e(i) -1.50203977E+00 -1.51499175E-03
p1 -6.72623299E-01

optvar inc
optph 100.000
optvl 6.72623299E+00
p2 2.25612350E-02

*** trajectory terminated by altmin = 4.00000000E+04 ft ***

```
*** trajectory terminated by altmin = 4.00000000E+04 ft ***

*** trajectory terminated by altmin = 4.00000000E+04 ft ***

*** trajectory terminated by altmin = 4.00000000E+04 ft ***
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 baseline with 10k fuel                                        problem
no.   1

*** iteration number   5



pert  1.27656273E-05     1.52861178E-03     3.27989336E-05     4.58976584E-07
5.02511349E-06     2.20290155E-05
     4.34671970E+00
du   -1.62400632E-02    -1.67687720E-03     2.38592037E-04    -1.95157503E-02
8.21912830E-05    -2.73530464E-04
     9.99676170E-01
partials of wprop  with respect to u(i)
smat  1.55140424E+03     1.68536855E+03     7.50960537E+04
4.39326683E+04     3.63053489E+03     9.93449686E+02
    -2.17133934E+02
partials of altito with respect to u(i)
smat -2.24964405E+01    -2.51661153E+01    -1.16576623E+03     -
6.14546097E+02    -6.20384218E+01    -1.17974202E+01
     5.59095202E-04
g1(i) -3.52856948E+00    -6.49673604E-01    -3.04631575E-02    -2.32504803E-
01    -3.05496229E-03    -8.98302527E-04
    -3.61996963E-02
g1mag  3.59571765E+00
g2(i)  4.25758783E+03     8.67231015E+02     3.86417719E+01
3.01415949E+02     3.73628963E+00     1.36318410E+00
    -1.11729423E+03
g2mag  3.93778218E+03
pg1(i)-1.62444544E-02     8.78797493E-02     3.75227534E-03     7.01803546E-
03     5.98975984E-04     1.46128315E-05
     1.95806528E-05
pg1mag 8.97241572E-02
nac          2
iac          1          2
ctha   9.00000000E+01
```

dp1ds -1.12956823E-01
dp2ds -1.?7355539E+01
stpmax 1.?0000000E+10
umag 2.61085602E+00
pctcc 1.50000000E-01
step 0.00000000E+00 1.22383876E-02 1.22383876E-02
0.00000000E+00 0.00000000E+00 0.00000000E+00
p1try -6.72618583E-01 -6.73936559E-01 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00
p2try 2.25612350E-02 2.94196299E-02 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00
yes 0.00000000E+00 0.00000000E+00 -6.80033483E-01
0.00000000E+00 0.00000000E+00 0.00000000E+00
nac 2
iac 1 2
dp1ds 2.67358726E-02
dp2ds 0.00000000E+00
stpmax 1.00000000E+10
umag 2.60808596E+00
dumag 4.93037491E-05
step 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00
p1try -6.73937911E-01 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00
p2try 2.94196299E-02 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00
yes 0.00000000E+00 0.00000000E+00 -6.80033483E-01
0.00000000E+00 0.00000000E+00 0.00000000E+00
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baseline with 10k fuel problem
no. 1

indvr bnkpc1 alppc1 alppc2 bnkpc2 alppc2
bnkpc2
critr
indph 40.000 40.000 60.000 60.000 70.000
70.000
70.000
u(i) 8.46940464E+01 1.20370425E+01 1.52161405E-02 -2.09482162E-
01 3.00497242E-02 -4.00203228E-02
1.42849406E+02

u= 8.469404638822E+01, 1.203704250155E+01, 1.521614047312E-02,
-2.094821621463E-01, 3.004972415744E-02,-4.002032284510E-0?,
1.428494057619E+02,

we(i) 1.71521514E-01 -1.59442425E-05
depvr wprop altito
depph 100.000 90.000
e(i) 1.71521514E+00 -1 59442425E-03
p1 -6.73937911E-01

optvar inc
optph 100.000
optvl 6.73937911E+00
p2 2.94196297E-02
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baseline with 10k fuel problem
no. 1

*** sensitivity analysis

dfdc 2.10072773E-04 -3.89123233E-03

*** problem solved

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baseline with 10k fuel problem
no. 1

input units = metric, output units = metric

initial state vector conditions
inc = 0.00000000E+00, altp = 3.00000000E+02, alta = 3.00000000E+02,
truan = 0.00000000E+00,
argp = 0.00000000E+00, lan = 0.00000000E+00,

program termination parameters

fesn = 100.000, maxtim = 1.00000000E+04, altmin = 4.00000000E+04,
altmax = 1.00000000E+20,

the launch pad inertial (l) frame is defined by
latl = 0.00000000E+00, lonl = 0.00000000E+00, azl = 0.00000000E+00,

attracting planet model
re = 6.37816586E+06, rp = 6.37816586E+06, omega = 7.29211000E-05,
mu = 3.98603195E+14,
j2 = 0.00000000E+00, j3 = 0.00000000E+00, j4 = 0.00000000E+00, j5
= 0.00000000E+00,
j6 = 0.00000000E+00, j7 = 0.00000000E+00, j8 = 0.00000000E+00,

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no. 1

begin phase 10.000

heat rate calculated using chapmans equation
heatk1 = 1.00000000E+00, heatk2 = 1.10274510E+08, heatk3 =
7.92480000E+03, rn = 3.04800000E-01,
rhosl = 1.22500434E+00,

generalized n-stage vehicle weight parameters
wgtsg = 5.00000000E+04, wpld = 0.00000000E+00, wprop =
1.00000000E+04, wjett = 0.00000000E+00,
go = 9.80663520E+00,

compute conic parameters

number of integrals for this phase = 7
integration scheme = laplace
dt = 1.00000000E+00, pinc = 5.00000000E+02,

use inertial angle of attack, sideslip, and bank commands: alphi, betai, banki
alppc = 0.00000000E+00, 0.00000000E+00, 0.00000000E+00,
0.00000000E+00,
betpc = 0.00000000E+00, 0.00000000E+00, 0.00000000E+00,
0.00000000E+00,
bnkpc = 0.00000000E+00, 0.00000000E+00, 0.00000000E+00,
0.00000000E+00,

alpha = 0.00000000E+00, dalpha = 0.00000000E+00, desn = 0.00000000E+00,
beta = 0.00000000E+00, dbeta = 0.00000000E+00, desn = 0.00000000E+00,
bnkang = 0.00000000E+00, dbank = 0.00000000E+00, desn =
0.00000000E+00,

the next event to occur will be one of the following:
esn = 20.000, type = primary, critr = time , value =
5.00000000E+00,
tol = 1.00000000E-06, mdl = 1,

tables and multipliers for this phase
none

special aerodynamic tables multipliers for this phase
none

program control flags
npc (1) = 1, npc (2) = 3, npc (3) = 5, npc (4) = 2, npc (5) = 0, npc (6) =
0, npc (7) = 0,
npc (8) = 0, npc (9) = 0, npc (10) = 0, npc (11) = 0, npc (12) = 0, npc (13)
= 0, npc (14) = 0,
npc (15) = 1, npc (16) = 1, npc (17) = 0, npc (18) = 0, npc (19) = 1, npc (20)
= 0, npc (21) = 0,
npc (22) = 0, npc (23) = 0, npc (24) = 0, npc (25) = 0, npc (26) = 0, npc (27)
= 0, npc (28) = 0,
npc (29) = 0, npc (30) = 0, npc (31) = 0, npc (32) = 0, npc (33) = 0, npc (34)
= 0, npc (35) = 0,
npc (36) = 0, npc (37) = 0, npc (38) = 0, npc (39) = 0, npc (40) = 0,

guidance (steering) control flags
iguid (1) = 3, iguid (2) = 0, iguid (3) = 1, iguid (4) = 0, iguid (5) = 1, iguid (6) =
0, iguid (7) = 0,
iguid (8) = 0, iguid (9) = 0, iguid (10) = 0, iguid (11) = 0, iguid (12) = 2, iguid (13)
= 1, iguid (14) = 0,
iguid (15) = 0, iguid (16) = 0, iguid (17) = 0, iguid (18) = 0, iguid (19) = 0, iguid
(20) = 0, iguid (21) = 0,
iguid (22) = 0, iguid (23) = 0, iguid (24) = 0, iguid (25) = 0,

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the file id and parameter list for this data file are

ud265 file 10000

time times tdurp dens pres atem altito gcrad gdlat gclat
long longi veli gammai azveli xi vxi axi velr gammar
azvelr yi vyi ayi vela gammaa azvela zi vzi azi
gamad azvad dwnrng crrng dprng1 dprng2 thrust weight wdot weicon
wprop asmg eta etal ipnull iynull incpch incyaw ftxb faxb
axb alpha alpdot alptot ftyb fayb ayb beta betdot qalpha
ftzb fazb azb bnkang bnkdot qaltot ca cd drag roli
yawr rolbd cn cl lift yawi pitr pitbd cy heatrt
tlheat piti rolr yawbd dynp mach reyno asxi asyi aszi
alta altp inc energy vcirc mass genv1 genv2 genv3 rgenv
xmax1

*** phase 10.000 ***

time 0.00000000E+00 times 0.00000000E+00 tdurp 0.00000000E+00 dens
0.00000000E+00 pres 0.00000000E+00 atem 0.00000000E+00
altito 3.00000000E+05 gcrad 6.67816586E+06 gdlat 0.00000000E+00 gclat
0.00000000E+00 long 0.00000000E+00 longi 0.00000000E+00
veli 7.72577023E+03 gammai 0.00000000E+00 azveli 9.00000000E+01 xi
6.67816586E+06 vxi 0.00000000E+00 axi -8.93771237E+00
velr 7.23879103E+03 gammar 0.00000000E+00 azvelr 9.00000000E+01 yi
0.00000000E+00 vyi 7.72577023E+03 ayi 0.00000000E+00
vela 7.23879103E+03 gammaa 0.00000000E+00 azvela 9.00000000E+01 zi
0.00000000E+00 vzi 0.00000000E+00 azi 0.00000000E+00
gamad 7.07429176E-02 azvad 0.00000000E+00 dwnrng 0.00000000E+00 crrng
0.00000000E+00 dprng1 0.00000000E+00 dprng2 0.00000000E+00
thrust 0.00000000E+00 weight 5.00000000E+04 wdot 0.00000000E+00 weicon
0.00000000E+00 wprop 1.00000000E+04 asmg 0.00000000E+00
eta 1.00000000E+00 etal 0.00000000E+00 ipnull 0.00000000E+00 iynull
0.00000000E+00 incpch 0.00000000E+00 incyaw 0.00000000E+00
ftxb 0.00000000E+00 faxb 0.00000000E+00 axb 0.00000000E+00 alpha
0.00000000E+00 alpdot 0.00000000E+00 alptot 0.00000000E+00
ftyb 0.00000000E+00 fayb 0.00000000E+00 ayb 0.00000000E+00 beta
0.00000000E+00 betdot 0.00000000E+00 qalpha 0.00000000E+00
ftzb 0.00000000E+00 fazb 0.00000000E+00 azb 0.00000000E+00 bnkang
0.00000000E+00 bnkdot 0.00000000E+00 qaltot 0.00000000E+00
ca 0.00000000E+00 cd 0.00000000E+00 drag 0.00000000E+00 roli -
9.00000000E+01 yawr 9.00000000E+01 rolbd 0.00000000E+00

cn 0.00000000E+00 cl 0.00000000E+00 lift 0.00000000E+00 yawi 0.00000000E+00 pitr 0.00000000E+00 pitbd 0.00000000E+00
cy 0.00000000E+00 heatrt 0.00000000E+00 tlheat 0.00000000E+00 piti -9.00000000E+01 rolr 0.00000000E+00 yawbd 0.00000000E+00
dynp 0.00000000E+00 mach 0.00000000E+00 reyno 0.00000000E+00 asxi 0.00000000E+00 asyi 0.00000000E+00 aszi 0.00000000E+00
alta 3.00000000E+02 altp 3.00000000E+02 inc 0.00000000E+00 energy-2.98437628E+07 vcirc 7.72577023E+03 mass 5.09858876E+03
genv1 0.00000000E+00 genv2 0.00000000E+00 genv3 0.00000000E+00 rgenv 0.00000000E+00 xmax1 0.00000000E+00
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*** phase 10.000 ***

time 5.00000000E+00 times 5.00000000E+00 tdurp 5.00000000E+00 dens 0.00000000E+00 pres 0.00000000E+00 atem 0.00000000E+00
altito 3.00000000E+05 gcrad 6.67816586E+06 gdlat 0.00000000E+00 gclat 0.00000000E+00 long 3.10528507E-01 longi 3.31418863E-01
veli 7.72577023E+03 gammai-2.63475995E-16 azveli 9.00000000E+01 xi 6.67805414E+06 vxi -4.46883126E+01 axi -8.93756285E+00
velr 7.23879103E+03 gammar-2.81200961E-16 azvelr 9.00000000E+01 yi 3.86286357E+04 vyi 7.72564098E+03 ayi -5.16985715E-02
vela 7.23879103E+03 gammaa-2.81200961E-16 azvela 9.00000000E+01 zi 0.00000000E+00 vzi 0.00000000E+00 azi 0.00000000E+00
gamad -7.03002404E-17 azvad 0.00000000E+00 dwnrng 0.00000000E+00 crrng 0.00000000E+00 dprng1 0.00000000E+00 dprng2 0.00000000E+00
thrust 0.00000000E+00 weight 5.00000000E+04 wdot 0.00000000E+00 weicon 0.00000000E+00 wprop 1.00000000E+04 asmg 0.00000000E+00
eta 1.00000000E+00 etal 0.00000000E+00 ipnull 0.00000000E+00 iynull 0.00000000E+00 incpch 0.00000000E+00 incyaw 0.00000000E+00
ftxb 0.00000000E+00 faxb 0.00000000E+00 axb 0.00000000E+00 alpha 0.00000000E+00 alpdot 0.00000000E+00 alptot 0.00000000E+00
ftyb 0.00000000E+00 fayb 0.00000000E+00 ayb 0.00000000E+00 beta 0.00000000E+00 betdot 0.00000000E+00 qalpha 0.00000000E+00
ftzb 0.00000000E+00 fazb 0.00000000E+00 azb 0.00000000E+00 bnkang 0.00000000E+00 bnkdot 0.00000000E+00 qaltot 0.00000000E+00
ca 0.00000000E+00 cd 0.00000000E+00 drag 0.00000000E+00 roli -9.00000000E+01 yawr 9.00000000E+01 rolbd 0.00000000E+00

cn 0.00000000E+00 cl 0.00000000E+00 lift 0.00000000E+00 yawi 0.00000000E+00 pitr -3.47873168E-16 pitbd 0.00000000E+00
cy 0.00000000E+00 heatrt 0.00000000E+00 tlheat 0.00000000E+00 piti -9.03314189E+01 rolr 0.00000000E+00 yawbd 0.00000000E+00
dynp 0.00000000E+00 mach 0.00000000E+00 reyno 0.00000000E+00 asxi 0.00000000E+00 asyi 0.00000000E+00 aszi 0.00000000E+00
alta 3.00000000E+02 altp 3.00000000E+02 inc 0.00000000E+00 energy-2.98437628E+07 vcirc 7.72577023E+03 mass 5.09858876E+03
genv1 0.00000000E+00 genv2 0.00000000E+00 genv3 0.00000000E+00 rgenv 0.00000000E+00 xmax1 0.00000000E+00

end of phase 10.000
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baseline with 10k fuel problem no. 1

begin phase 20.000

heat rate calculated using chapmans equation
heatk1 = 1.00000000E+00, heatk2 = 1.10274510E+08, heatk3 = 7.92480000E+03, rn = 3.04800000E-01,
rhosl = 1.22500434E+00,

propulsion activated: the following engines are on:
1 rocket engines : 1,

propulsion flowrate calculation mode and engine indices:
1 constant ispv : 1,

generalized n-stage vehicle weight parameters
wgtsg = 5.00000000E+04, wpld = 0.00000000E+00, wprop = 1.00000000E+04, wjett = 0.00000000E+00,
go = 9.80663520E+00,

compute conic parameters

number of integrals for this phase = 8
integration scheme = fourth order runge-kutta
dt = 1.00000000E+00, pinc = 5.00000000E+02,

use inertial angle of attack, sideslip, and bank commands: alphi, betai, banki

alppc = 1.80000000E+02, 0.00000000E+00, 0.00000000E+00,
0.00000000E+00,
betpc = 0.00000000E+00, 0.00000000E+00, 0.00000000E+00,
0.00000000E+00,
bnkpc = 0.00000000E+00, 0.00000000E+00, 0.00000000E+00,
0.00000000E+00,
alpha = 0.00000000E+00, dalpha = 0.00000000E+00, desn = 0.00000000E+00,
beta = 0.00000000E+00, dbeta = 0.00000000E+00, desn = 0.00000000E+00,
bnkang = 0.00000000E+00, dbank = 0.00000000E+00, desn =
0.00000000E+00,

the next event to occur will be one of the following:
esn = 30.000, type = primary, critr = altp , value =
5.00000000E+01,
tol = 1.00000000E-02, mdl = 1,

tables and multipliers for this phase
(tvc1t , 1.0000000E+00, one) (

special aerodynamic tables multipliers for this phase
none

program control flags
npc (1) = 1, npc (2) = 1, npc (3) = 5, npc (4) = 2, npc (5) = 0, npc (6) =
0, npc (7) = 0,
npc (8) = 0, npc (9) = 1, npc (10) = 0, npc (11) = 0, npc (12) = 0, npc (13)
= 0, npc (14) = 0,
npc (15) = 1, npc (16) = 1, npc (17) = 0, npc (18) = 0, npc (19) = 1, npc (20)
= 0, npc (21) = 0,
npc (22) = 0, npc (23) = 0, npc (24) = 0, npc (25) = 0, npc (26) = 0, npc (27)
= 0, npc (28) = 0,
npc (29) = 0, npc (30) = 0, npc (31) = 0, npc (32) = 0, npc (33) = 0, npc (34)
= 0, npc (35) = 0,
npc (36) = 0, npc (37) = 0, npc (38) = 0, npc (39) = 0, npc (40) = 0,

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no. 1

guidance (steering) control flags
iguid (1) = 3, iguid (2) = 0, iguid (3) = 1, iguid (4) = 0, iguid (5) = 1, iguid (6) =
0, iguid (7) = 0,

iguid (8) = 0, iguid (9) = 0, iguid (10) = 0, iguid (11) = 0, iguid (12) = 2, iguid (13) = 1, iguid (14) = 0,
iguid (15) = 0, iguid (16) = 0, iguid (17) = 0, iguid (18) = 0, iguid (19) = 0, iguid (20) = 0, iguid (21) = 0,
iguid (22) = 0, iguid (23) = 0, iguid (24) = 0, iguid (25) = 0,

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baseline with 10k fuel problem no. 1

*** phase 20.000 ***

time 5.00000000E+00 times 0.00000000E+00 tdurp 0.00000000E+00 dens 0.00000000E+00 pres 0.00000000E+00 atem 0.00000000E+00
altito 3.00000000E+05 gcrad 6.67816586E+06 gdlat 0.00000000E+00 gclat 0.00000000E+00 long 3.10528507E-01 longi 3.31418863E-01
veli 7.72577023E+03 gammai-2.63475995E-16 azveli 9.00000000E+01 xi 6.67805414E+06 vxi -4.46883126E+01 axi -8.92054544E+00
velr 7.23879103E+03 gammar-2.81200961E-16 azvelr 9.00000000E+01 yi 3.86286357E+04 vyi 7.72564098E+03 ayi -2.99363991E+00
vela 7.23879103E+03 gammaa-2.81200961E-16 azvela 9.00000000E+01 zi 0.00000000E+00 vzi 0.00000000E+00 azi 0.00000000E+00
gamad -7.03002404E-17 azvad 0.00000000E+00 dwnrng 0.00000000E+00 crrng 0.00000000E+00 dprng1 0.00000000E+00 dprng2 0.00000000E+00
thrust 1.50000000E+04 weight 5.00000000E+04 wdot 5.00000000E+01 weicon 0.00000000E+00 wprop 1.00000000E+04 asmg 3.00000000E-01
eta 1.00000000E+00 etal 1.00000000E+00 ipnull 0.00000000E+00 iynull 0.00000000E+00 incpch 0.00000000E+00 incyaw 0.00000000E+00
ftxb 1.50000000E+04 faxb 0.00000000E+00 axb 2.94199056E+00 alpha 1.80000000E+02 alpdot 0.00000000E+00 alptot 8.33479650E-14
ftyb 0.00000000E+00 fayb 0.00000000E+00 ayb 0.00000000E+00 beta 0.00000000E+00 betdot 0.00000000E+00 qalpha 0.00000000E+00
ftzb 0.00000000E+00 fazb 0.00000000E+00 azb 0.00000000E+00 bnkang 0.00000000E+00 bnkdot 0.00000000E+00 qaltot 0.00000000E+00
ca 0.00000000E+00 cd 0.00000000E+00 drag 0.00000000E+00 roli -9.00000000E+01 yawr 2.70000000E+02 rolbd 0.00000000E+00
cn 0.00000000E+00 cl 0.00000000E+00 lift 0.00000000E+00 yawi 0.00000000E+00 pitr 8.36883451E-14 pitbd 0.00000000E+00
cy 0.00000000E+00 heatrt 0.00000000E+00 tlheat 0.00000000E+00 piti 8.96685811E+01 rolr 1.80000000E+02 yawbd 0.00000000E+00

dynp 0.00000000E+00 mach 0.00000000E+00 reyno 0.00000000E+00 asxi 1.70174093E-02 asyi -2.94194134E+00 aszi 0.00000000E+00
alta 3.00000000E+02 altp 3.00000000E+02 inc 0.00000000E+00 energy-2.98437628E+07 vcirc 7.72577023E+03 mass 5.09858876E+03
genv1 0.00000000E+00 genv2 0.00000000E+00 genv3 0.00000000E+00 rgenv 0.00000000E+00 xmax1 0.00000000E+00

*** phase 20.000 ***

time 2.98517671E+01 times 2.48517671E+01 tdurp 2.48517671E+01 dens 0.00000000E+00 pres 0.00000000E+00 atem 0.00000000E+00
altito 2.99982562E+05 gcrad 6.67814842E+06 gdlat 0.00000000E+00 gclat 0.00000000E+00 long 1.84610713E+00 longi 1.97082994E+00
veli 7.65175304E+03 gammai-1.57692685E-02 azveli 9.00000000E+01 xi 6.67419806E+06 vxi -2.65253760E+02 axi -8.82788661E+00
velr 7.16477513E+03 gammar-1.68410797E-02 azvelr 9.00000000E+01 yi 2.29666124E+05 vyi 7.64715405E+03 ayi -3.32252991E+00
vela 7.16477513E+03 gammaa-1.68410797E-02 azvela 9.00000000E+01 zi 0.00000000E+00 vzi 0.00000000E+00 azi 0.00000000E+00
gamad -1.36359670E-03 azvad 0.00000000E+00 dwnrng 0.00000000E+00 crrng 0.00000000E+00 dprng1 0.00000000E+00 dprng2 0.00000000E+00
thrust 1.50000000E+04 weight 4.87574116E+04 wdot 5.00000000E+01 weicon 1.24258835E+03 wprop 8.75741165E+03 asmg 3.07645535E-01
eta 1.00000000E+00 etal 1.00000000E+00 ipnull 0.00000000E+00 iynull 0.00000000E+00 incpch 0.00000000E+00 incyaw 0.00000000E+00
ftxb 1.50000000E+04 faxb 0.00000000E+00 axb 3.01696753E+00 alpha -1.79998928E+02 alpdot 0.00000000E+00 alptot 1.07181112E-03
ftyb 0.00000000E+00 fayb 0.00000000E+00 ayb 0.00000000E+00 beta 0.00000000E+00 betdot 0.00000000E+00 qalpha 0.00000000E+00
ftzb 0.00000000E+00 fazb 0.00000000E+00 azb 0.00000000E+00 bnkang 0.00000000E+00 bnkdot 0.00000000E+00 qaltot 0.00000000E+00
ca 0.00000000E+00 cd 0.00000000E+00 drag 0.00000000E+00 roli -9.00000000E+01 yawr 2.70000000E+02 rolbd 0.00000000E+00
cn 0.00000000E+00 cl 0.00000000E+00 lift 0.00000000E+00 yawi 0.00000000E+00 pitr 1.57692685E-02 pitbd 0.00000000E+00
cy 0.00000000E+00 heatrt 0.00000000E+00 tlheat 0.00000000E+00 piti 8.80134008E+01 rolr 1.80000000E+02 yawbd 0.00000000E+00
dynp 0.00000000E+00 mach 0.00000000E+00 reyno 0.00000000E+00 asxi 1.04585443E-01 asyi -3.01515422E+00 aszi 0.00000000E+00
alta 2.99995571E+02 altp 5.00069997E+01 inc 0.00000000E+00 energy-3.04130191E+07 vcirc 7.72578031E+03 mass 4.97187982E+03
genv1 0.00000000E+00 genv2 0.00000000E+00 genv3 0.00000000E+00 rgenv 0.00000000E+00 xmax1 0.00000000E+00

end of phase 20.000
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baseline with 10k fuel problem
no. 1

begin phase 30.000

heat rate calculated using chapmans equation
heatk1 = 1.00000000E+00, heatk2 = 1.10274510E+08, heatk3 =
7.92480000E+03, rn = 3.04800000E-01,
rhosl = 1.22500434E+00,

generalized n-stage vehicle weight parameters
wgtsg = 4.87574116E+04, wpld = 0.00000000E+00, wprop =
8.75741165E+03, wjett = 0.00000000E+00,
go = 9.80663520E+00,

compute conic parameters

number of integrals for this phase = 7
integration scheme = laplace
dt = 1.00000000E+00, pinc = 5.00000000E+02,

use inertial angle of attack, sideslip, and bank commands: alphi, betai, banki
alppc = 0.00000000E+00, 0.00000000E+00, 0.00000000E+00,
0.00000000E+00,
betpc = 0.00000000E+00, 0.00000000E+00, 0.00000000E+00,
0.00000000E+00,
bnkpc = 0.00000000E+00, 0.00000000E+00, 0.00000000E+00,
0.00000000E+00,
alpha = -1.79998928E+02, dalpha = 0.00000000E+00, desn = 0.00000000E+00,
beta = 0.00000000E+00, dbeta = 0.00000000E+00, desn = 0.00000000E+00,
bnkang = 0.00000000E+00, dbank = 0.00000000E+00, desn =
0.00000000E+00,

the next event to occur will be one of the following:
esn = 40.000, type = primary , critr = altito , value =
1.20000000E+05,
tol = 1.00000000E-02, mdl = 1,

tables and multipliers for this phase
(tvc1t , 1.0000000E+00, one) (

special aerodynamic tables multipliers for this phase
none

program control flags
npc (1) = 1, npc (2) = 3, npc (3) = 5, npc (4) = 2, npc (5) = 0, npc (6) = 0, npc (7) = 0,
npc (8) = 0, npc (9) = 0, npc (10) = 0, npc (11) = 0, npc (12) = 0, npc (13) = 0, npc (14) = 0,
npc (15) = 1, npc (16) = 1, npc (17) = 0, npc (18) = 0, npc (19) = 1, npc (20) = 0, npc (21) = 0,
npc (22) = 0, npc (23) = 0, npc (24) = 0, npc (25) = 0, npc (26) = 0, npc (27) = 0, npc (28) = 0,
npc (29) = 0, npc (30) = 0, npc (31) = 0, npc (32) = 0, npc (33) = 0, npc (34) = 0, npc (35) = 0,
npc (36) = 0, npc (37) = 0, npc (38) = 0, npc (39) = 0, npc (40) = 0,

guidance (steering) control flags
iguid (1) = 3, iguid (2) = 0, iguid (3) = 1, iguid (4) = 0, iguid (5) = 1, iguid (6) = 0, iguid (7) = 0,
iguid (8) = 0, iguid (9) = 0, iguid (10) = 0, iguid (11) = 0, iguid (12) = 2, iguid (13) = 1, iguid (14) = 0,
iguid (15) = 0, iguid (16) = 0, iguid (17) = 0, iguid (18) = 0, iguid (19) = 0, iguid (20) = 0, iguid (21) = 0,
iguid (22) = 0, iguid (23) = 0, iguid (24) = 0, iguid (25) = 0,

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*** phase 30.000 ***
time 2.98517671E+01 times 0.00000000E+00 tdurp 0.00000000E+00 dens 0.00000000E+00 pres 0.00000000E+00 atem 0.00000000E+00
altito 2.99982562E+05 gcrad 6.67814842E+06 gdlat 0.00000000E+00 gclat 0.00000000E+00 long 1.84610713E+00 longi 1.97082994E+00
veli 7.65175304E+03 gammai-1.57692685E-02 azveli 9.00000000E+01 xi 6.67419806E+06 vxi -2.65253760E+02 axi -8.93247205E+00

velr 7.16477513E+03 gammar-1.68410797E-02 azvelr 9.00000000E+01 yi 2.29666124E+05 vyi 7.64715405E+03 ayi -3.07375690E-01
vela 7.16477513E+03 gammaa-1.68410797E-02 azvela 9.00000000E+01 zi 0.00000000E+00 vzi 0.00000000E+00 azi 0.00000000E+00
gamad -1.36359670E-03 azvad 0.00000000E+00 dwnrng 0.00000000E+00 crrng 0.00000000E+00 dprng1 0.00000000E+00 dprng2 0.00000000E+00
thrust 0.00000000E+00 weight 4.87574116E+04 wdot 0.00000000E+00 weicon 1.24258835E+03 wprop 8.75741165E+03 asmg 0.00000000E+00
eta 1.00000000E+00 etal 1.00000000E+00 ipnull 0.00000000E+00 iynull 0.00000000E+00 incpch 0.00000000E+00 incyaw 0.00000000E+00
ftxb 0.00000000E+00 faxb 0.00000000E+00 axb 0.00000000E+00 alpha 1.07181112E-03 alpdot 0.00000000E+00 alptot 1.07181112E-03
ftyb 0.00000000E+00 fayb 0.00000000E+00 ayb 0.00000000E+00 beta 0.00000000E+00 betdot 0.00000000E+00 qalpha 0.00000000E+00
ftzb 0.00000000E+00 fazb 0.00000000E+00 azb 0.00000000E+00 bnkang 0.00000000E+00 bnkdot 0.00000000E+00 qaltot 0.00000000E+00
ca 0.00000000E+00 cd 0.00000000E+00 drag 0.00000000E+00 roli -9.00000000E+01 yawr 9.00000000E+01 rolbd 0.00000000E+00
cn 0.00000000E+00 cl 0.00000000E+00 lift 0.00000000E+00 yawi 0.00000000E+00 pitr -1.57692685E-02 pitbd 0.00000000E+00
cy 0.00000000E+00 heatrt 0.00000000E+00 tlheat 0.00000000E+00 piti -9.19865992E+01 rolr 0.00000000E+00 yawbd 0.00000000E+00
dynp 0.00000000E+00 mach 0.00000000E+00 reyno 0.00000000E+00 asxi 0.00000000E+00 asyi 0.00000000E+00 aszi 0.00000000E+00
alta 2.99995571E+02 altp 5.00069997E+01 inc 0.00000000E+00 energy-3.04130191E+07 vcirc 7.72578031E+03 mass 4.97187982E+03
genv1 0.00000000E+00 genv2 0.00000000E+00 genv3 0.00000000E+00 rgenv 0.00000000E+00 xmax1 0.00000000E+00

*** phase 30.000 ***

time 1.73458869E+03 times 1.70473692E+03 tdurp 1.70473692E+03 dens 0.00000000E+00 pres 0.00000000E+00 atem 0.00000000E+00
altito 1.20000000E+05 gcrad 6.49816586E+06 gdlat 0.00000000E+00 gclat 0.00000000E+00 long 1.09032849E+02 longi 1.16280084E+02
veli 7.86484053E+03 gammai-9.81445330E-01 azveli 9.00000000E+01 xi -2.87712497E+06 vxi -6.99125327E+03 axi 4.17952691E+00
velr 7.39106110E+03 gammar-1.04436438E+00 azvelr 9.00000000E+01 yi 5.82651795E+06 vyi -3.60251222E+03 ayi -8.46403575E+00
vela 7.39106110E+03 gammaa-1.04436438E+00 azvela 9.00000000E+01 zi 0.00000000E+00 vzi 0.00000000E+00 azi 0.00000000E+00
gamad 6.16855302E-04 azvad 0.00000000E+00 dwnrng 0.00000000E+00 crrng 0.00000000E+00 dprng1 0.00000000E+00 dprng2 0.00000000E+00

thrust 0.00000000E+00 weight 4.87574116E+04 wdot 0.00000000E+00 weicon 1.24258835E+03 wprop 8.75741165E+03 asmg 0.00000000E+00
eta 1.00000000E+00 etal 1.00000000E+00 ipnull 0.00000000E+00 iynull 0.00000000E+00 incpch 0.00000000E+00 incyaw 0.00000000E+00
ftxb 0.00000000E+00 faxb 0.00000000E+00 axb 0.00000000E+00 alpha 6.29190522E-02 alpdot 0.00000000E+00 alptot 6.29190522E-02
ftyb 0.00000000E+00 fayb 0.00000000E+00 ayb 0.00000000E+00 beta 0.00000000E+00 betdot 0.00000000E+00 qalpha 0.00000000E+00
ftzb 0.00000000E+00 fazb 0.00000000E+00 azb 0.00000000E+00 bnkang 0.00000000E+00 bnkdot 0.00000000E+00 qaltot 0.00000000E+00
ca 0.00000000E+00 cd 0.00000000E+00 drag 0.00000000E+00 roli -9.00000000E+01 yawr 9.00000000E+01 rolbd 0.00000000E+00
cn 0.00000000E+00 cl 0.00000000E+00 lift 0.00000000E+00 yawi 0.00000000E+00 pitr -9.81445330E-01 pitbd 0.00000000E+00
cy 0.00000000E+00 heatrt 0.00000000E+00 tlheat 0.00000000E+00 piti 1.52738471E+02 rolr 0.00000000E+00 yawbd 0.00000000E+00
dynp 0.00000000E+00 mach 0.00000000E+00 reyno 0.00000000E+00 asxi 0.00000000E+00 asyi 0.00000000E+00 aszi 0.00000000E+00
alta 2.99995565E+02 altp 5.00070053E+01 inc 0.00000000E+00 energy-3.04130191E+07 vcirc 7.83204172E+03 mass 4.97187982E+03
genv1 0.00000000E+00 genv2 0.00000000E+00 genv3 0.00000000E+00 rgenv 0.00000000E+00 xmax1 0.00000000E+00

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begin phase 40.000

1976 u.s. standard atmosphere model

heat rate calculated using chapmans equation
heatk1 = 1.00000000E+00, heatk2 = 1.10274510E+08, heatk3 = 7.92480000E+03, rn = 3.04800000E-01,
rhosl = 1.22500434E+00,

generalized n-stage vehicle weight parameters
wgtsg = 4.87574116E+04, wpld = 0.00000000E+00, wprop = 8.75741165E+03, wjett = 0.00000000E+00,
go = 9.80663520E+00,

compute conic parameters

aerodynamic coefficients specified by drag and lift coefficients
sref = 1.64800000E+01, lref = 7.70000000E+00, lrefy = 0.00000000E+00,

number of integrals for this phase = 9
integration scheme = fourth order runge-kutta
dt = 1.00000000E+00, pinc = 3.00000000E+01,

use angle of attack, sideslip, and bank commands: alpha, beta, bnkang
alppc = 1.20370425E+01, 0.00000000E+00, 0.00000000E+00, 0.00000000E+00,
betpc = 0.00000000E+00, 0.00000000E+00, 0.00000000E+00, 0.00000000E+00,
bnkpc = 8.46940464E+01, 0.00000000E+00, 0.00000000E+00, 0.00000000E+00,
alpha = 6.29190522E-02, dalpha = 0.00000000E+00, desn = 0.00000000E+00,
beta = 0.00000000E+00, dbeta = 0.00000000E+00, desn = 0.00000000E+00,
bnkang = 0.00000000E+00, dbank = 0.00000000E+00, desn = 0.00000000E+00,

the next event to occur will be one of the following:
esn = 60.000, type = primary, critr = tdurp , value = 4.80000000E+02,
tol = 1.00000000E-02, mdl = 1,

tables and multipliers for this phase
(cdt , 1.0000000E+00, one) (clt , 1.0000000E+00, one) (tvc1t , 1.0000000E+00, one)

special aerodynamic tables multipliers for this phase
(cdt , one) (clt , one) (

program control flags
npc (1) = 1, npc (2) = 1, npc (3) = 5, npc (4) = 2, npc (5) = 5, npc (6) = 0, npc (7) = 0,
npc (8) = 2, npc (9) = 0, npc (10) = 0, npc (11) = 0, npc (12) = 0, npc (13) = 0, npc (14) = 0,
npc (15) = 1, npc (16) = 1, npc (17) = 0, npc (18) = 0, npc (19) = 1, npc (20) = 0, npc (21) = 0,
npc (22) = 0, npc (23) = 0, npc (24) = 0, npc (25) = 0, npc (26) = 0, npc (27) = 0, npc (28) = 0,

npc (29) = 0, npc (30) = 0, npc (31) = 0, npc (32) = 0, npc (33) = 0, npc (34) = 0, npc (35) = 0,
npc (36) = 0, npc (37) = 0, npc (38) = 0, npc (39) = 0, npc (40) = 0,

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guidance (steering) control flags
iguid (1) = 0, iguid (2) = 1, iguid (3) = 0, iguid (4) = 0, iguid (5) = 1, iguid (6) = 1, iguid (7) = 0,
iguid (8) = 1, iguid (9) = 0, iguid (10) = 0, iguid (11) = 0, iguid (12) = 2, iguid (13) = 1, iguid (14) = 0,
iguid (15) = 0, iguid (16) = 0, iguid (17) = 0, iguid (18) = 0, iguid (19) = 0, iguid (20) = 0, iguid (21) = 0,
iguid (22) = 0, iguid (23) = 0, iguid (24) = 0, iguid (25) = 0,

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*** phase 40.000 ***

time 1.73458869E+03 times 0.00000000E+00 tdurp 0.00000000E+00 dens 2.22200757E-08 pres 2.53672693E-03 atem 3.60000000E+02
altito 1.20000000E+05 gcrad 6.49816586E+06 gdlat 0.00000000E+00 gclat 0.00000000E+00 long 1.09032849E+02 longi 1.16280084E+02
veli 7.86484053E+03 gammai-9.81445330E-01 azveli 9.00000000E+01 xi -2.67712497E+06 vxi -6.99125327E+03 axi 4.17975971E+00
velr 7.39106110E+03 gammar-1.04436438E+00 azvelr 9.00000000E+01 yi 5.82651795E+06 vyi -3.60251222E+03 ayi -8.46386038E+00
vela 7.39106110E+03 gammaa-1.04436438E+00 azvela 9.00000000E+01 zi 0.00000000E+00 vzi 0.00000000E+00 azi -5.27006233E-04
gamad 6.17234719E-04 azvad 4.08605061E-06 dwnrng 0.00000000E+00 crrng 0.00000000E+00 dprng1 0.00000000E+00 dprng2 0.00000000E+00
thrust 0.00000000E+00 weight 4.87574116E+04 wdot 0.00000000E+00 weicon 1.24258835E+03 wprop 8.75741165E+03 asmg 6.14105754E-05
eta 1.00000000E+00 etal 1.00000000E+00 ipnull 0.00000000E+00 iynull 0.00000000E+00 incpch 0.00000000E+00 incyaw 0.00000000E+00

ftxb 0.00000000E+00 faxb -8.48317335E-01 axb -1.70623057E-04 alpha
1.20370425E+01 alpdot 0.00000000E+00 alptot 1.20370425E+01
ftyb 0.00000000E+00 fayb 0.00000000E+00 ayb 0.00000000E+00 beta
3.52521831E-15 betdot 0.00000000E+00 qalpha 7.30548271E+00
ftzb 0.00000000E+00 fazb -2.87153536E+00 azb -5.77555263E-04 bnkang
8.46940464E+01 bnkdot 0.00000000E+00 qaltot 7.30548271E+00
ca 8.48148720E-02 cd 1.42822299E-01 drag 1.42850693E+00 roli -
1.74032205E+02 yawr 1.01984710E+02 rolbd -1.42694634E-02
cn 2.87096460E-01 cl 2.63096429E-01 lift 2.63148733E+00 yawi -
2.71976725E+01 pitr 8.34151786E-02 pitbd -6.35062394E-03
cy 0.00000000E+00 heatrt 2.15965722E+04 tlheat 0.00000000E+00 piti -
1.70698435E+02 rolr 8.45931725E+01 yawbd 6.69201351E-02
dynp 6.06916750E-01 mach 2.71088604E+01 reyno 5.97309042E+01 asxi
2.32792065E-04 asyi 1.75369878E-04 aszi -5.27006233E-04
alta 2.99995565E+02 altp 5.00070053E+01 inc 0.00000000E+00 energy-
3.04130191E+07 vcirc 7.83204172E+03 mass 4.97187982E+03
genv1 0.00000000E+00 genv2 0.00000000E+00 genv3 0.00000000E+00 rgenv
0.00000000E+00 xmax1 2.15965722E+04

*** phase 40.000 ***

time 2.21458869E+03 times 4.80000000E+02 tdurp 4.80000000E+02 dens
1.11674560E-04 pres 7.22950889E+00 atem 2.25521740E+02
altito 6.78334480E+04 gcrad 6.44599930E+06 gdlat -1.25308906E-01 gclat -
1.25308906E-01 long 1.40533054E+02 longi 1.49785764E+02
veli 7.81394719E+03 gammai-5.54465973E-01 azveli 9.15096263E+01 xi -
5.57029563E+06 vxi -3.86496752E+03 axi 8.82497746E+00
velr 7.34409596E+03 gammar-5.89940108E-01 azvelr 9.16062418E+01 yi
3.24384262E+06 vyi -6.78804034E+03 ayi -3.40814738E+00
vela 7.34409596E+03 gammaa-5.89940108E-01 azvela 9.16062418E+01 zi -
1.40977308E+04 vzi -2.05682161E+02 azi -2.55375303E+00
gamad 9.52239132E-04 azvad 2.02390639E-02 dwnrng 0.00000000E+00 crrng
0.00000000E+00 dprng1 0.00000000E+00 dprng2 0.00000000E+00
thrust 0.00000000E+00 weight 4.87574116E+04 wdot 0.00000000E+00 weicon
1.24258835E+03 wprop 8.75741165E+03 asmg 3.04729839E-01
eta 1.00000000E+00 etal 1.00000000E+00 ipnull 0.00000000E+00 iynull
0.00000000E+00 incpch 0.00000000E+00 incyaw 0.00000000E+00
ftxb 0.00000000E+00 faxb -4.20949654E+03 axb -8.46660961E-01 alpha
1.20370425E+01 alpdot 0.00000000E+00 alptot 1.20370425E+01
ftyb 0.00000000E+00 fayb 0.00000000E+00 ayb 0.00000000E+00 beta
7.04009005E-15 betdot 0.00000000E+00 qalpha 3.62510619E+04
ftzb 0.00000000E+00 fazb -1.42490524E+04 azb -2.86592857E+00 bnkang
8.46940464E+01 bnkdot 0.00000000E+00 qaltot 3.62510619E+04

ca 8.48148720E-02 cd 1.42822299E-01 drag 7.08849711E+03 roli -1.69596560E+02 yawr 1.03591456E+02 rolbd -1.45263491E-02
cn 2.87096460E-01 cl 2.63096429E-01 lift 1.30578928E+04 yawi -6.01159055E+01 pitr 5.27934074E-01 pitbd 1.39692489E-02
cy 0.00000000E+00 heatrt 1.50061252E+06 tlheat 2.12550229E+08 piti -1.75396273E+02 rolr 8.46875371E+01 yawbd 6.85696916E-02
dynp 3.01162531E+03 mach 2.43949092E+01 reyno 4.29616828E+05 asxi 5.35097201E-01 asyi 1.41943605E+00 aszi -2.57473370E+00
alta 8.87485341E+01 altp -1.13576748E+02 inc 1.51481693E+00 energy-3.13084150E+07 vcirc 7.86366965E+03 mass 4.97187982E+03
genv1 0.00000000E+00 genv2 0.00000000E+00 genv3 0.00000000E+00 rgenv 0.00000000E+00 xmax1 1.50061252E+06

end of phase 40.000
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begin phase 60.000

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heat rate calculated using chapmans equation
heatk1 = 1.00000000E+00, heatk2 = 1.10274510E+08, heatk3 = 7.92480000E+03, rn = 3.04800000E-01,
rhosl = 1.22500434E+00,

propulsion activated: the following engines are on:
1 rocket engines : 1,

propulsion flowrate calculation mode and engine indices:
1 constant ispv : 1,

generalized n-stage vehicle weight parameters
wgtsg = 4.87574116E+04, wpld = 0.00000000E+00, wprop = 8.75741165E+03, wjett = 0.00000000E+00,
go = 9.80663520E+00,

compute conic parameters

aerodynamic coefficients specified by drag and lift coefficients

sref = 1.64800000E+01, lref = 7.70000000E+00, lrefy = 0.00000000E+00,

number of integrals for this phase = 10
integration scheme = fourth order runge-kutta
dt = 1.00000000E+00, pinc = 1.00000000E+01,

use angle of attack, sideslip, and bank commands: alpha, beta, bnkang
alppc = 1.20370425E+01, 1.52161405E-02, 0.00000000E+00,
0.00000000E+00,
betpc = 7.04009005E-15, 0.00000000E+00, 0.00000000E+00,
0.00000000E+00,
bnkpc = 8.46940464E+01, -2.09482162E-01, 0.00000000E+00,
0.00000000E+00,
alpha = 1.20370425E+01, dalpha = 0.00000000E+00, desn = 0.00000000E+00,
beta = 7.04009005E-15, dbeta = 0.00000000E+00, desn = 0.00000000E+00,
bnkang = 8.46940464E+01, dbank = 0.00000000E+00, desn =
0.00000000E+00,

the next event to occur will be one of the following:
esn = 70.000, type = roving , critr = tdurp , value =
1.42849406E+02,
tol = 1.00000000E-02, mdl = 1,
esn = 80.000, type = roving , critr = altito , value =
1.20000000E+05,
tol = 1.00000000E-02, mdl = 1,
esn = 90.000, type = primary , critr = altito , value =
3.00000000E+05,
tol = 1.00000000E-02, mdl = 1,

tables and multipliers for this phase
(cdt , 1.0000000E+00, one) (clt , 1.0000000E+00, one) (tvclt ,
1.0000000E+00, one)

special aerodynamic tables multipliers for this phase
(cdt , one) (clt , one) (

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program control flags

npc (1) = 1, npc (2) = 1, npc (3) = 5, npc (4) = 2, npc (5) = 5, npc (6) = 0, npc (7) = 0,
npc (8) = 2, npc (9) = 1, npc (10) = 0, npc (11) = 0, npc (12) = 0, npc (13) = 0, npc (14) = 0,
npc (15) = 1, npc (16) = 1, npc (17) = 0, npc (18) = 0, npc (19) = 1, npc (20) = 0, npc (21) = 0,
npc (22) = 0, npc (23) = 0, npc (24) = 0, npc (25) = 0, npc (26) = 0, npc (27) = 0, npc (28) = 0,
npc (29) = 0, npc (30) = 0, npc (31) = 0, npc (32) = 0, npc (33) = 0, npc (34) = 0, npc (35) = 0,
npc (36) = 0, npc (37) = 0, npc (38) = 0, npc (39) = 0, npc (40) = 0,

guidance (steering) control flags
iguid (1) = 0, iguid (2) = 0, iguid (3) = 0, iguid (4) = 0, iguid (5) = 1, iguid (6) = 1, iguid (7) = 0,
iguid (8) = 1, iguid (9) = 0, iguid (10) = 0, iguid (11) = 0, iguid (12) = 2, iguid (13) = 1, iguid (14) = 0,
iguid (15) = 0, iguid (16) = 0, iguid (17) = 0, iguid (18) = 0, iguid (19) = 0, iguid (20) = 0, iguid (21) = 0,
iguid (22) = 0, iguid (23) = 0, iguid (24) = 0, iguid (25) = 0,

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*** phase 60.000 ***
time 2.21458869E+03 times 0.00000000E+00 tdurp 0.00000000E+00 dens 1.11674560E-04 pres 7.22950889E+00 atem 2.25521740E+02
altito 6.78334480E+04 gcrad 6.44599930E+06 gdlat -1.25308906E-01 gclat -1.25308906E-01 long 1.40533054E+02 longi 1.49785764E+02
veli 7.81394719E+03 gammai-5.54465973E-01 azveli 9.15096263E+01 xi -5.57029563E+06 vxi -3.86496752E+03 axi 7.32663205E+00
velr 7.34409596E+03 gammar-5.89940108E-01 azvelr 9.16062418E+01 yi 3.24384262E+06 vyi -6.78804034E+03 ayi -5.92893338E+00
vela 7.34409596E+03 gammaa-5.89940108E-01 azvela 9.16062418E+01 zi -1.40977308E+04 vzi -2.05682161E+02 azi -3.26276086E+00
gamad 1.40615210E-03 azvad 2.51268344E-02 dwnrng 0.00000000E+00 crrng 0.00000000E+00 dprng1 0.00000000E+00 dprng2 0.00000000E+00
thrust 1.50000000E+04 weight 4.87574116E+04 wdot 5.00000000E+01 weicon 1.24258835E+03 wprop 8.75741165E+03 asmg 3.66585017E-01

eta 1.00000000E+00 etal 1.00000000E+00 ipnull 0.00000000E+00 iynull
0.00000000E+00 incpch 0.00000000E+00 incyaw 0.00000000E+00
ftxb 1.50000000E+04 faxb -4.20949654E+03 axb 2.17030657E+00 alpha
1.20370425E+01 alpdot 1.52161405E-02 alptot 1.20370425E+01
ftyb 0.00000000E+00 fayb 0.00000000E+00 ayb 0.00000000E+00 beta
1.05878520E-14 betdot 0.00000000E+00 qalpha 3.62510619E+04
ftzb 0.00000000E+00 fazb -1.42490524E+04 azb -2.86592857E+00 bnkang
8.46940464E+01 bnkdot-2.09482162E-01 qaltot 3.62510619E+04
ca 8.48148720E-02 cd 1.42822299E-01 drag 7.08849711E+03 roli -
1.69596560E+02 yawr 1.03591456E+02 rolbd -2.19353403E-01
cn 2.87096460E-01 cl 2.63096429E-01 lift 1.30578928E+04 yawi -
6.01159055E+01 pitr 5.27934074E-01 pitbd 3.40939335E-02
cy 0.00000000E+00 heatrt 1.50061252E+06 tlheat 2.12550229E+08 piti -
1.75396273E+02 rolr 8.46875371E+01 yawbd 2.48939317E-02
dynp 3.01162531E+03 mach 2.43949092E+01 reyno 4.29616828E+05 asxi -
9.63248204E-01 asyi -1.10134995E+00 aszi -3.28374152E+00
alta 8.87485341E+01 altp -1.13576748E+02 inc 1.51481693E+00 energy-
3.13084150E+07 vcirc 7.86366965E+03 mass 4.97187982E+03
genv1 0.00000000E+00 genv2 0.00000000E+00 genv3 0.00000000E+00 rgenv
0.00000000E+00 xmax1 1.50061252E+06

*** phase 60.000 ***

time 2.35743809E+03 times 1.42849406E+02 tdurp 1.42849405E+02 dens
7.80186862E-05 pres 4.89156536E+00 atem 2.18415319E+02
altito 7.04269576E+04 gcrad 6.44859281E+06 gdlat -7.97818255E-01 gclat -
7.97818255E-01 long 1.49915812E+02 longi 1.59765356E+02
veli 7.93625843E+03 gammai 1.25736366E+00 azveli 9.61634109E+01 xi -
6.05002531E+06 vxi -2.88061078E+03 axi 6.53790145E+00
velr 7.46907358E+03 gammar 1.33602463E+00 azvelr 9.65507701E+01 yi
2.23013017E+06 vyi -7.34551604E+03 ayi -4.06091663E+00
vela 7.46907358E+03 gammaa 1.33602463E+00 azvela 9.65507701E+01 zi -
8.97908861E+04 vzi -8.54209271E+02 azi -2.98668798E+00
gamad 1.70786223E-02 azvad 2.11940796E-02 dwnrng 0.00000000E+00 crrng
0.00000000E+00 dprng1 0.00000000E+00 dprng2 0.00000000E+00
thrust 1.50000000E+04 weight 4.16149414E+04 wdot 5.00000000E+01 weicon
8.38505864E+03 wprop 1.61494136E+03 asmg 4.11935790E-01
eta 1.00000000E+00 etal 1.00000000E+00 ipnull 0.00000000E+00 iynull
0.00000000E+00 incpch 0.00000000E+00 incyaw 0.00000000E+00
ftxb 1.50000000E+04 faxb -3.32882568E+03 axb 2.75033306E+00 alpha
1.42106591E+01 alpdot 1.52161405E-02 alptot 1.42106591E+01
ftyb 0.00000000E+00 fayb 0.00000000E+00 ayb 0.00000000E+00 beta
1.52617428E-14 betdot 0.00000000E+00 qalpha 3.09254719E+04

ftzb 0.00000000E+00 fazb -1.25560860E+04 azb -2.95886408E+00 bnkang
5.47696440E+01 bnkdot-2.09482162E-01 qaltot 3.09254719E+04
ca 9.28178989E-02 cd 1.75923463E-01 drag 6.30932772E+03 roli -
1.13158999E+02 yawr 1.08279742E+02 rolbd -2.17883381E-01
cn 3.50102299E-01 cl 3.16603407E-01 lift 1.13546801E+04 yawi -
5.21741221E+01 pitr 9.44944356E+00 pitbd 2.49744538E-03
cy 0.00000000E+00 heatrt 1.32274218E+06 tlheat 4.63632347E+08 piti
1.40607929E+02 rolr 5.58785665E+01 yawbd 3.01657191E-03
dynp 2.17621657E+03 mach 2.52104304E+01 reyno 3.13491646E+05 asxi -
2.45506768E+00 asyi -7.45973180E-01 aszi -3.12015629E+00
alta 3.85622703E+02 altp 4.44517473E+00 inc 6.21463516E+00 energy-
3.03203316E+07 vcirc 7.86208818E+03 mass 4.24354944E+03
genv1 0.00000000E+00 genv2 0.00000000E+00 genv3 0.00000000E+00 rgenv
0.00000000E+00 xmax1 1.95696303E+06

end of phase 60.000
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no. 1

begin phase 70.000

1976 u.s. standard atmosphere model

heat rate calculated using chapmans equation
heatk1 = 1.00000000E+00, heatk2 = 1.10274510E+08, heatk3 =
7.92480000E+03, rn = 3.04800000E-01,
rhosl = 1.22500434E+00,

generalized n-stage vehicle weight parameters
wgtsg = 4.16149414E+04, wpld = 0.00000000E+00, wprop =
1.61494136E+03, wjett = 0.00000000E+00,
go = 9.80663520E+00,

compute conic parameters

aerodynamic coefficients specified by drag and lift coefficients
sref = 1.64800000E+01, lref = 7.70000000E+00, lrefy = 0.00000000E+00,

number of integrals for this phase = 9
integration scheme = fourth order runge-kutta

dt = 1.00000000E+00, pinc = 5.00000000E+01,

use angle of attack, sideslip, and bank commands: alpha, beta, bnkang
alppc = 1.42106591E+01, 3.00497242E-02, 0.00000000E+00,
0.00000000E+00,
betpc = 1.52617428E-14, 0.00000000E+00, 0.00000000E+00,
0.00000000E+00,
bnkpc = 5.47696440E+01, -4.00203228E-02, 0.00000000E+00,
0.00000000E+00,
alpha = 1.42106591E+01, dalpha = 0.00000000E+00, desn = 0.00000000E+00,
beta = 1.52617428E-14, dbeta = 0.00000000E+00, desn = 0.00000000E+00,
bnkang = 5.47696440E+01, dbank = 0.00000000E+00, desn =
0.00000000E+00,

the next event to occur will be one of the following:
esn = 80.000, type = roving , critr = altito , value =
1.20000000E+05,
tol = 1.00000000E-02, mdl = 1,
esn = 90.000, type = primary , critr = altito , value =
3.00000000E+05,
tol = 1.00000000E-02, mdl = 1,

tables and multipliers for this phase
(cdt , 1.0000000E+00, one) (clt , 1.0000000E+00, one) (tvclt ,
1.0000000E+00, one)

special aerodynamic tables multipliers for this phase
(cdt , one) (clt , one) (

program control flags
npc (1) = 1, npc (2) = 1, npc (3) = 5, npc (4) = 2, npc (5) = 5, npc (6) =
0, npc (7) = 0,
npc (8) = 2, npc (9) = 0, npc (10) = 0, npc (11) = 0, npc (12) = 0, npc (13)
= 0, npc (14) = 0,
npc (15) = 1, npc (16) = 1, npc (17) = 0, npc (18) = 0, npc (19) = 1, npc (20)
= 0, npc (21) = 0,
npc (22) = 0, npc (23) = 0, npc (24) = 0, npc (25) = 0, npc (26) = 0, npc (27)
= 0, npc (28) = 0,
npc (29) = 0, npc (30) = 0, npc (31) = 0, npc (32) = 0, npc (33) = 0, npc (34)
= 0, npc (35) = 0,
npc (36) = 0, npc (37) = 0, npc (38) = 0, npc (39) = 0, npc (40) = 0,

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no. 1

guidance (steering) control flags
iguid (1) = 0, iguid (2) = 0, iguid (3) = 0, iguid (4) = 0, iguid (5) = 1, iguid (6) = 1, iguid (7) = 0,
iguid (8) = 1, iguid (9) = 0, iguid (10) = 0, iguid (11) = 0, iguid (12) = 2, iguid (13) = 1, iguid (14) = 0,
iguid (15) = 0, iguid (16) = 0, iguid (17) = 0, iguid (18) = 0, iguid (19) = 0, iguid (20) = 0, iguid (21) = 0,
iguid (22) = 0, iguid (23) = 0, iguid (24) = 0, iguid (25) = 0,

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baseline with 10k fuel problem
no. 1

*** phase 70.000 ***

time 2.35743809E+03 times 0.00000000E+00 tdurp 0.00000000E+00 dens 7.80186862E-05 pres 4.89156536E+00 atem 2.18415319E+02
altito 7.04269576E+04 gcrad 6.44859281E+06 gdlat -7.97818255E-01 gclat -7.97818255E-01 long 1.49915812E+02 longi 1.59765356E+02
veli 7.93625843E+03 gammai 1.25736366E+00 azveli 9.61634109E+01 xi -6.05002531E+06 vxi -2.88061078E+03 axi 8.21318574E+00
velr 7.46907358E+03 gammar 1.33602463E+00 azvelr 9.65507701E+01 yi 2.23013017E+06 vyi -7.34551604E+03 ayi -1.14982312E+00
vela 7.46907358E+03 gammaa 1.33602463E+00 azvela 9.65507701E+01 zi -8.97908861E+04 vzi -8.54209271E+02 azi -1.88505104E+00
gamad 1.32387039E-02 azvad 1.57552878E-02 dwnrng 0.00000000E+00 crrng 0.00000000E+00 dprng1 0.00000000E+00 dprng2 0.00000000E+00
thrust 0.00000000E+00 weight 4.16149414E+04 wdot 0.00000000E+00 weicon 8.38505864E+03 wprop 1.61494136E+03 asmg 3.12144058E-01
eta 1.00000000E+00 etal 1.00000000E+00 ipnull 0.00000000E+00 iynull 0.00000000E+00 incpch 0.00000000E+00 incyaw 0.00000000E+00
ftxb 0.00000000E+00 faxb -3.32882568E+03 axb -7.84443713E-01 alpha 1.42106591E+01 alpdot 3.00497242E-02 alptot 1.42106591E+01
ftyb 0.00000000E+00 fayb 0.00000000E+00 ayb 0.00000000E+00 beta 2.22385395E-14 betdot 0.00000000E+00 qalpha 3.09254719E+04

ftzb 0.00000000E+00 fazb -1.25560860E+04 azb -2.95886408E+00 bnkang 5.47696440E+01 bnkdot-4.00203228E-02 qaltot 3.09254719E+04
ca 9.28178989E-02 cd 1.75923463E-01 drag 6.30932772E+03 roli - 1.13158999E+02 yawr 1.08279742E+02 rolbd -5.34841952E-02
cn 3.50102299E-01 cl 3.16603407E-01 lift 1.13546801E+04 yawi - 5.21741221E+01 pitr 9.44944356E+00 pitbd 1.06745023E-02
cy 0.00000000E+00 heatrt 1.32274218E+06 tlheat 4.63632347E+08 piti 1.40607929E+02 rolr 5.58785665E+01 yawbd 4.46485053E-02
dynp 2.17621657E+03 mach 2.52104304E+01 reyno 3.13491646E+05 asxi - 7.79783396E-01 asyi 2.16512033E+00 aszi -2.01851935E+00
alta 3.85622703E+02 altp 4.44517473E+00 inc 6.21463516E+00 energy- 3.03203316E+07 vcirc 7.86208818E+03 mass 4.24354944E+03
genv1 0.00000000E+00 genv2 0.00000000E+00 genv3 0.00000000E+00 rgenv 0.00000000E+00 xmax1 1.95696303E+06

*** phase 70.000 ***

time 2.57720192E+03 times 2.19763826E+02 tdurp 2.19763826E+02 dens 2.22200846E-08 pres 2.53672764E-03 atem 3.59999960E+02
altito 1.19999997E+05 gcrad 6.49816585E+06 gdlat -2.51280202E+00 gclat - 2.51280202E+00 long 1.64195879E+02 longi 1.74963612E+02
veli 7.82379130E+03 gammai 1.70739714E+00 azveli 9.62554111E+01 xi - 6.46685319E+06 vxi -8.77220059E+02 axi 9.39356768E+00
velr 7.35361532E+03 gammar 1.81660031E+00 azvelr 9.66575165E+01 yi 5.69915060E+05 vyi -7.72657739E+03 ayi -8.26970541E-01
vela 7.35361532E+03 gammaa 1.81660031E+00 azvela 9.66575165E+01 zi - 2.84896557E+05 vzi -8.61508617E+02 azi 4.13093208E-01
gamad -1.40162779E-04 azvad -3.16571505E-03 dwnrng 0.00000000E+00 crrng 0.00000000E+00 dprng1 0.00000000E+00 dprng2 0.00000000E+00
thrust 0.00000000E+00 weight 4.16149414E+04 wdot 0.00000000E+00 weicon 8.38505864E+03 wprop 1.61494136E+03 asmg 1.40637529E-04
eta 1.00000000E+00 etal 1.00000000E+00 ipnull 0.00000000E+00 iynull 0.00000000E+00 incpch 0.00000000E+00 incyaw 0.00000000E+00
ftxb 0.00000000E+00 faxb -1.24129562E+00 axb -2.92513527E-04 alpha 2.08145015E+01 alpdot 3.00497242E-02 alptot 2.08145015E+01
ftyb 0.00000000E+00 fayb 0.00000000E+00 ayb 0.00000000E+00 beta 3.98606545E-14 betdot 0.00000000E+00 qalpha 1.25049956E+01
ftzb 0.00000000E+00 fazb -5.71947337E+00 azb -1.34780411E-03 bnkang 4.59746248E+01 bnkdot-4.00203228E-02 qaltot 1.25049956E+01
ca 1.25371980E-01 cd 3.22461691E-01 drag 3.19266141E+00 roli - 9.06927249E+01 yawr 1.12075912E+02 rolbd -5.54663708E-02
cn 5.77671985E-01 cl 4.95420543E-01 lift 4.90510995E+00 yawi - 4.86385717E+01 pitr 1.60492117E+01 pitbd -1.80919654E-02

cy 0.00000000E+00 heatrt 2.12537895E+04 tlheat 5.39446030E+08 piti 1.20716931E+02 rolr 4.84016477E+01 yawbd 3.19336171E-02
dynp 6.00782852E-01 mach 2.69715172E+01 reyno 5.94283147E+01 asxi -6.66948284E-04 asyi 9.30701264E-04 aszi -7.68840177E-04
alta 3.00034767E+02 altp -8.73439949E+01 inc 6.73937911E+00 energy- 3.07350223E+07 vcirc 7.83204172E+03 mass 4.24354944E+03
genv1 0.00000000E+00 genv2 0.00000000E+00 genv3 0.00000000E+00 rgenv 0.00000000E+00 xmax1 1.95696303E+06

end of phase 70.000
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baseline with 10k fuel problem no. 1

begin phase 80.000

heat rate calculated using chapmans equation
heatk1 = 1.00000000E+00, heatk2 = 1.10274510E+08, heatk3 = 7.92480000E+03, rn = 3.04800000E-01,
rhosl = 1.22500434E+00,

generalized n-stage vehicle weight parameters
wgtsg = 4.16149414E+04, wpld = 0.00000000E+00, wprop = 1.61494136E+03, wjett = 0.00000000E+00,
go = 9.80663520E+00,

compute conic parameters

number of integrals for this phase = 7
integration scheme = laplace
dt = 1.00000000E+00, pinc = 1.00000000E+02,

use inertial angle of attack, sideslip, and bank commands: alphi, betai, banki
alppc = 0.00000000E+00, 0.00000000E+00, 0.00000000E+00, 0.00000000E+00,
betpc = 1.52617428E-14, 0.00000000E+00, 0.00000000E+00, 0.00000000E+00,
bnkpc = 0.00000000E+00, 0.00000000E+00, 0.00000000E+00, 0.00000000E+00,
alpha = 2.08145015E+01, dalpha = 0.00000000E+00, desn = 0.00000000E+00,
beta = 3.98606545E-14, dbeta = 0.00000000E+00, desn = 0.00000000E+00,

bnkang = 4.59746248E+01, dbank = 0.00000000E+00, desn =
0.00000000E+00,

the next event to occur will be one of the following:
esn = 90.000, type = primary, critr = altito, value =
3.00000000E+05,
tol = 1.00000000E-02, mdl = 1,

tables and multipliers for this phase
(cdt , 1.0000000E+00, one) (clt , 1.0000000E+00, one) (tvc1t ,
1.0000000E+00, one)

special aerodynamic tables multipliers for this phase
(cdt , one) (clt , one) (

program control flags
npc (1) = 1, npc (2) = 3, npc (3) = 5, npc (4) = 2, npc (5) = 0, npc (6) =
0, npc (7) = 0,
npc (8) = 0, npc (9) = 0, npc (10) = 0, npc (11) = 0, npc (12) = 0, npc (13)
= 0, npc (14) = 0,
npc (15) = 1, npc (16) = 1, npc (17) = 0, npc (18) = 0, npc (19) = 1, npc (20)
= 0, npc (21) = 0,
npc (22) = 0, npc (23) = 0, npc (24) = 0, npc (25) = 0, npc (26) = 0, npc (27)
= 0, npc (28) = 0,
npc (29) = 0, npc (30) = 0, npc (31) = 0, npc (32) = 0, npc (33) = 0, npc (34)
= 0, npc (35) = 0,
npc (36) = 0, npc (37) = 0, npc (38) = 0, npc (39) = 0, npc (40) = 0,

guidance (steering) control flags
iguid (1) = 3, iguid (2) = 0, iguid (3) = 1, iguid (4) = 0, iguid (5) = 1, iguid (6) =
1, iguid (7) = 0,
iguid (8) = 1, iguid (9) = 0, iguid (10) = 0, iguid (11) = 0, iguid (12) = 2, iguid (13)
= 1, iguid (14) = 0,
iguid (15) = 0, iguid (16) = 0, iguid (17) = 0, iguid (18) = 0, iguid (19) = 0, iguid
(20) = 0, iguid (21) = 0,
iguid (22) = 0, iguid (23) = 0, iguid (24) = 0, iguid (25) = 0,

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baseline with 10k fuel problem
no. 1

*** phase 80.000 ***

time 2.57720192E+03 times 0.00000000E+00 tdurp 0.00000000E+00 dens 0.00000000E+00 pres 0.00000000E+00 atem 0.00000000E+00
altito 1.19999997E+05 gcrad 6.49816585E+06 gdlat -2.51280202E+00 gclat -2.51280202E+00 long 1.64195879E+02 longi 1.74963612E+02
veli 7.82379130E+03 gammai 1.70739714E+00 azveli 9.62554111E+01 xi -6.46685319E+06 vxi -8.77220059E+02 axi 9.39423463E+00
velr 7.35361532E+03 gammar 1.81660031E+00 azvelr 9.66575165E+01 yi 5.69915060E+05 vyi -7.72657739E+03 ayi -8.27901242E-01
vela 7.35361532E+03 gammaa 1.81660031E+00 azvela 9.66575165E+01 zi -2.84896557E+05 vzi -8.61508617E+02 azi 4.13862048E-01
gamad -1.40162779E-04 azvad -3.16571505E-03 dwnrng 0.00000000E+00 crrng 0.00000000E+00 dprng1 0.00000000E+00 dprng2 0.00000000E+00
thrust 0.00000000E+00 weight 4.16149414E+04 wdot 0.00000000E+00 weicon 8.38505864E+03 wprop 1.61494136E+03 asmg 0.00000000E+00
eta 1.00000000E+00 etal 1.00000000E+00 ipnull 0.00000000E+00 iynull 0.00000000E+00 incpch 0.00000000E+00 incyaw 0.00000000E+00
ftxb 0.00000000E+00 faxb 0.00000000E+00 axb 0.00000000E+00 alpha -1.09247881E-01 alpdot 0.00000000E+00 alptot 4.16486713E-01
ftyb 0.00000000E+00 fayb 0.00000000E+00 ayb 0.00000000E+00 beta 4.01903320E-01 betdot 0.00000000E+00 qalpha 0.00000000E+00
ftzb 0.00000000E+00 fazb 0.00000000E+00 azb 0.00000000E+00 bnkang 1.27470894E-02 bnkdot 0.00000000E+00 qaltot 0.00000000E+00
ca 0.00000000E+00 cd 0.00000000E+00 drag 0.00000000E+00 roli -8.39808199E+01 yawr 9.62554111E+01 rolbd 0.00000000E+00
cn 0.00000000E+00 cl 0.00000000E+00 lift 0.00000000E+00 yawi -3.03688355E+00 pitr 1.70739714E+00 pitbd 0.00000000E+00
cy 0.00000000E+00 heatrt 0.00000000E+00 tlheat 5.39446030E+08 piti 9.64467528E+01 rolr 0.00000000E+00 yawbd 0.00000000E+00
dynp 0.00000000E+00 mach 0.00000000E+00 reyno 0.00000000E+00 asxi 0.00000000E+00 asyi 0.00000000E+00 aszi 0.00000000E+00
alta 3.00034767E+02 altp -8.73439949E+01 inc 6.73937911E+00 energy-3.07350223E+07 vcirc 7.83204172E+03 mass 4.24354944E+03
genv1 0.00000000E+00 genv2 0.00000000E+00 genv3 0.00000000E+00 rgenv 0.00000000E+00 xmax1 1.95696303E+06

*** phase 80.000 ***

time 3.82652282E+03 times 1.24932090E+03 tdurp 1.24932090E+03 dens 0.00000000E+00 pres 0.00000000E+00 atem 0.00000000E+00
altito 2.99999998E+05 gcrad 6.67816586E+06 gdlat -6.50455510E+00 gclat -6.50455510E+00 long 2.42412342E+02 longi 2.58399827E+02

veli 7.60953393E+03 gammai 3.24307703E-02 azveli 8.82326787E+01 xi -
1.33420737E+06 vxi 7.44435311E+03 axi 1.78563426E+00
velr 7.12593535E+03 gammar 3.46316710E-02 azvelr 8.81126981E+01 yi -
6.49965164E+06 vyi -1.55963817E+03 ayi 8.69879816E+00
vela 7.12593535E+03 gammaa 3.46316710E-02 azvela 8.81126981E+01 zi -
7.56517346E+05 vzi 2.32684580E+02 azi 1.01248376E+00
gamad -2.14613564E-03 azvad -7.94576025E-03 dwnrng 0.00000000E+00 crrng
0.00000000E+00 dprng1 0.00000000E+00 dprng2 0.00000000E+00
thrust 0.00000000E+00 weight 4.16149414E+04 wdot 0.00000000E+00 weicon
8.38505864E+03 wprop 1.61494136E+03 asmg 0.00000000E+00
eta 1.00000000E+00 etal 1.00000000E+00 ipnull 0.00000000E+00 iynull
0.00000000E+00 incpch 0.00000000E+00 incyaw 0.00000000E+00
ftxb 0.00000000E+00 faxb 0.00000000E+00 axb 0.00000000E+00 alpha -
2.20097665E-03 alpdot 0.00000000E+00 alptot 1.20000733E-01
ftyb 0.00000000E+00 fayb 0.00000000E+00 ayb 0.00000000E+00 beta -
1.19980547E-01 betdot 0.00000000E+00 qalpha 0.00000000E+00
ftzb 0.00000000E+00 fazb 0.00000000E+00 azb 0.00000000E+00 bnkang-
7.25207588E-05 bnkdot 0.00000000E+00 qaltot 0.00000000E+00
ca 0.00000000E+00 cd 0.00000000E+00 drag 0.00000000E+00 roli -
8.39808199E+01 yawr 8.82326787E+01 rolbd 0.00000000E+00
cn 0.00000000E+00 cl 0.00000000E+00 lift 0.00000000E+00 yawi -
3.03688355E+00 pitr 3.24307703E-02 pitbd 0.00000000E+00
cy 0.00000000E+00 heatrt 0.00000000E+00 tlheat 5.39446030E+08 piti
1.15733350E+01 rolr -7.95138798E-16 yawbd 0.00000000E+00
dynp 0.00000000E+00 mach 0.00000000E+00 reyno 0.00000000E+00 asxi
0.00000000E+00 asyi 0.00000000E+00 aszi 0.00000000E+00
alta 3.00034747E+02 altp -8.73439772E+01 inc 6.73937911E+00 energy-
3.07350223E+07 vcirc 7.72577023E+03 mass 4.24354944E+03
genv1 0.00000000E+00 genv2 0.00000000E+00 genv3 0.00000000E+00 rgenv
0.00000000E+00 xmax1 1.95696303E+06

end of phase 80.000
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begin phase 90.000

heat rate calculated using chapmans equation
heatk1 = 1.00000000E+00, heatk2 = 1.10274510E+08, heatk3 =
7.92480000E+03, rn = 3.04800000E-01,

rhosl = 1.22500434E+00,

circularize orbit at current altitude
dvimag = 1.16317294E+02, thrusting engine number = 1
ispv = 3.00000000E+02, pitrdv = -2.12212181E+00, yawrdv = 0.00000000E+00,

generalized n-stage vehicle weight parameters
wgtsg = 4.16149414E+04, wpld = 0.00000000E+00, wprop =
1.61494136E+03, wjett = 0.00000000E+00,
go = 9.80663520E+00,

compute conic parameters

number of integrals for this phase = 7
integration scheme = laplace
dt = 1.00000000E+00, pinc = 1.00000000E+02,

use inertial angle of attack, sideslip, and bank commands: alphi, betai, banki
alppc = 0.00000000E+00, 0.00000000E+00, 0.00000000E+00,
0.00000000E+00,
betpc = 1.52617428E-14, 0.00000000E+00, 0.00000000E+00,
0.00000000E+00,
bnkpc = 0.00000000E+00, 0.00000000E+00, 0.00000000E+00,
0.00000000E+00,
alpha = -2.20097665E-03, dalpha = 0.00000000E+00, desn = 0.00000000E+00,
beta = -1.19980547E-01, dbeta = 0.00000000E+00, desn = 0.00000000E+00,
bnkang = -7.25207588E-05, dbank = 0.00000000E+00, desn =
0.00000000E+00,

the next event to occur will be one of the following:
esn = 100.000, type = primary, critr = tdurp , value =
5.00000000E+00,
tol = 1.00000000E-02, mdl = 1,

tables and multipliers for this phase
(cdt , 1.0000000E+00, one) (clt , 1.0000000E+00, one) (tvclt ,
1.0000000E+00, one)

special aerodynamic tables multipliers for this phase
(cdt , one) (clt , one) (

program control flags

npc (1) = 1, npc (2) = 3, npc (3) = 5, npc (4) = 2, npc (5) = 0, npc (6) = 0, npc (7) = 0,
npc (8) = 0, npc (9) = 3, npc (10) = 0, npc (11) = 0, npc (12) = 0, npc (13) = 0, npc (14) = 0,
npc (15) = 1, npc (16) = 1, npc (17) = 0, npc (18) = 0, npc (19) = 1, npc (20) = 0, npc (21) = 0,
npc (22) = 0, npc (23) = 0, npc (24) = 0, npc (25) = 0, npc (26) = 0, npc (27) = 0, npc (28) = 0,
npc (29) = 0, npc (30) = 0, npc (31) = 0, npc (32) = 0, npc (33) = 0, npc (34) = 0, npc (35) = 0,
npc (36) = 0, npc (37) = 0, npc (38) = 0, npc (39) = 0, npc (40) = 0,

guidance (steering) control flags
iguid (1) = 3, iguid (2) = 0, iguid (3) = 1, iguid (4) = 0, iguid (5) = 1, iguid (6) = 1, iguid (7) = 0,
iguid (8) = 1, iguid (9) = 0, iguid (10) = 0, iguid (11) = 0, iguid (12) = 2, iguid (13) = 1, iguid (14) = 0,
iguid (15) = 0, iguid (16) = 0, iguid (17) = 0, iguid (18) = 0, iguid (19) = 0, iguid (20) = 0, iguid (21) = 0,
iguid (22) = 0, iguid (23) = 0, iguid (24) = 0, iguid (25) = 0,

1execution date and time Tue May 10 13:36:46 1994
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baseline with 10k fuel problem no. 1

*** phase 90.000 ***

time 3.82652282E+03 times 0.00000000E+00 tdurp 0.00000000E+00 dens 0.00000000E+00 pres 0.00000000E+00 atem 0.00000000E+00
altito 2.99999998E+05 gcrad 6.67816586E+06 gdlat -6.50455510E+00 gclat -6.50455510E+00 long 2.42412342E+02 longi 2.58399827E+02
veli 7.72577023E+03 gammai-1.10659918E-15 azveli 8.82326787E+01 xi -1.33420737E+06 vxi 7.55894113E+03 axi 1.78563426E+00
velr 7.24217131E+03 gammar-2.97933893E-15 azvelr 8.81146238E+01 yi -6.49965164E+06 vyi -1.57920595E+03 ayi 8.69879816E+00
vela 7.24217131E+03 gammaa-2.97933893E-15 azvela 8.81146238E+01 zi -7.56517346E+05 vzi 2.[illegible]34275E+02 azi 1.01248376E+00
gamad 5.40964514E-23 azvad -8.05873003E-03 dwnrng 0.00000000E+00 crrng 0.00000000E+00 dprng1 0.00000000E+00 dprng2 0.00000000E+00
thrust 0.00000000E+00 weight 4.00017152E+04 wdot 0.00000000E+00 weicon 9.99828478E+03 wprop 1.71522514E+00 asmg 0.00000000E+00

eta 1.00000000E+00 etal 1.00000000E+00 ipnull 0.00000000E+00 iynull 0.00000000E+00 incpch 0.00000000E+00 incyaw 0.00000000E+00
ftxb 0.00000000E+00 faxb 0.00000000E+00 axb 0.00000000E+00 alpha 1.15238826E-15 alpdot 0.00000000E+00 alptot 1.18054871E-01
ftyb 0.00000000E+00 fayb 0.00000000E+00 ayb 0.00000000E+00 beta -1.18054871E-01 betdot 0.00000000E+00 qalpha 0.00000000E+00
ftzb 0.00000000E+00 fazb 0.00000000E+00 azb 0.00000000E+00 bnkang 6.13877626E-18 bnkdot 0.00000000E+00 qaltot 0.00000000E+00
ca 0.00000000E+00 cd 0.00000000E+00 drag 0.00000000E+00 roli -8.39808199E+01 yawr 8.82326787E+01 rolbd 0.00000000E+00
cn 0.00000000E+00 cl 0.00000000E+00 lift 0.00000000E+00 yawi -3.03688355E+00 pitr -1.96299859E-15 pitbd 0.00000000E+00
cy 0.00000000E+00 heatrt 0.00000000E+00 tlheat 5.39446030E+08 piti 1.15409043E+01 rolr 0.00000000E+00 yawbd 0.00000000E+00
dynp 0.00000000E+00 mach 0.00000000E+00 reyno 0.00000000E+00 asxi 0.00000000E+00 asyi 0.00000000E+00 aszi 0.00000000E+00
alta 2.99999998E+02 altp 2.99999998E+02 inc 6.73937911E+00 energy-2.98437628E+07 vcirc 7.72577023E+03 mass 4.07904591E+03
genv1 0.00000000E+00 genv2 0.00000000E+00 genv3 0.00000000E+00 rgenv 0.00000000E+00 xmax1 1.95696303E+06

*** phase 90.000 ***

time 3.83152282E+03 times 5.00000000E+00 tdurp 5.00000000E+00 dens 0.00000000E+00 pres 0.00000000E+00 atem 0.00000000E+00
altito 2.99999998E+05 gcrad 6.67816586E+06 gdlat -6.49422479E+00 gclat -6.49422479E+00 long 2.42724852E+02 longi 2.58733227E+02
veli 7.72577023E+03 gammai-5.26951990E-16 azveli 8.81949401E+01 xi -1.29639056E+06 vxi 7.56774280E+03 axi 1.73502218E+00
velr 7.24217198E+03 gammar-5.62139370E-16 azvelr 8.80743627E+01 yi -6.50743889E+06 vyi -1.53568579E+03 ayi 8.70922021E+00
vela 7.24217198E+03 gammaa-5.62139370E-16 azvela 8.80743627E+01 zi -7.55321025E+05 vzi 2.41792705E+02 azi 1.01088266E+00
gamad -2.81069581E-17 azvad -8.04567643E-03 dwnrng 0.00000000E+00 crrng 0.00000000E+00 dprng1 0.00000000E+00 dprng2 0.00000000E+00
thrust 0.00000000E+00 weight 4.00017152E+04 wdot 0.00000000E+00 weicon 9.99828478E+03 wprop 1.71521514E+00 asmg 0.00000000E+00
eta 1.00000000E+00 etal 1.00000000E+00 ipnull 0.00000000E+00 iynull 0.00000000E+00 incpch 0.00000000E+00 incyaw 0.00000000E+00
ftxb 0.00000000E+00 faxb 0.00000000E+00 axb 0.00000000E+00 alpha 5.90247645E-16 alpdot 0.00000000E+00 alptot 1.20577406E-01
ftyb 0.00000000E+00 fayb 0.00000000E+00 ayb 0.00000000E+00 beta -1.20577406E-01 betdot 0.00000000E+00 qalpha 0.00000000E+00

ftzb 0.00000000E+00 fazb 0.00000000E+00 azb 0.00000000E+00 bnkang
7.96323440E-16 bnkdot C.00000000E+00 qaltot 0.00000000E+00
ca 0.00000000E+00 cd 0.00000000E+00 drag 0.00000000E+00 roli -
8.39808199E+01 yawr 8.81949401E+01 rolbd 0.00000000E+00
cn 0.00000000E+00 cl 0.00000000E+00 lift 0.00000000E+00 yawi -
3.03688355E+00 pitr -1.49088501E-16 pitbd 0.00000000E+00
cy 0.00000000E+00 heatrt 0.00000000E+00 tlheat 5.39446030E+08 piti
1.12094854E+01 rolr 7.95138670E-16 yawbd 0.00000000E+00
dynp 0.00000000E+00 mach 0.00000000E+00 reyno 0.00000000E+00 asxi
0.00000000E+00 asyi 0.00000000E+00 aszi 0.00000000E+00
alta 2.99999998E+02 altp 2.99999998E+02 inc 6.73937911E+00 energy-
2.98437628E+07 vcirc 7.72577023E+03 mass 4.07904591E+03
genv1 0.00000000E+00 genv2 0.00000000E+00 genv3 0.00000000E+00 rgenv
0.00000000E+00 xmax1 1.95696303E+06

end of phase 90.000

esn = 100.000 fesn= 100.000
time= 3.83152282E+03
normal termination
total cpu time required for problem = 479.350 sec

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